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Reaping the carbon rent: abatement and overallocation profits in the European cement industry, insights from an LMDI decomposition analysis

— *Pre-Print* —

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Abstract

We analyse variations of carbon emissions in the European cement industry from 1990 to 2012, at the European level (EU 27), and at the national level for six major producers (Germany, France, Spain, United Kingdom, Italy and Poland). We apply a Log-Mean Divisia Index (LMDI) method, cross-referencing data from three databases: the Getting the Numbers Right (GNR) database developed by the Cement Sustainability Initiative, the European Union Transaction Log (EUTL), and the Eurostat International Trade database.

Our decomposition method allows seven channels of emissions change to be distinguished: activity, clinker trade, clinker share, alternative fuels, thermal and electrical energy efficiency, and electricity decarbonisation. We find that, apart from a slow trend of emissions reductions coming from technological improvements (first from a decrease in the clinker share, then from an increase in alternative fuels), most of the emissions changes can be attributed to the activity effect.

Using counterfactual scenarios, we estimate that the introduction of the EU ETS brought small but positive technological abatement ($2.2\% \pm 1.3\%$ between 2005 and 2012). Moreover, we find that the European cement industry has gained 3.5 billion Euros of “overallocation profits”, mostly due to the slowdown of production.

Key-words

Cement Industry, LMDI, EU ETS, Abatement, Overallocation, Windfall Profits, Overallocation Profits, Carbon Emissions, Energy Efficiency

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1. Introduction

Cement is the most widely-used man-made material in the world (Moya et al., 2010), and also one of the most carbon-intensive products. The manufacture of cement accounts for approximately 5% of global anthropogenic emissions (IEA, 2009). China has the lion’s share of cement production with 58% of the 3,700 million tons produced in 2012. The European Union is now the third-biggest producer with 5% of global production, behind India with 7% (U.S. Geological Survey, 2013).

Since 2005 European cement emissions have been covered by the European Union Emission Trading Scheme (EU ETS), presented as Europe’s flagship policy to tackle climate change (Branger et al., 2013a). In this cap-and-trade system, installations can buy or sell tradable allowances to attain emissions caps. A key feature of the EU ETS, the question of whether allowances should be auctioned or received free of charge (and in the latter case, what should be the allocation plan, or the number of allowances per installation), has proved to be a very controversial topic (Boemare and Quirion, 2002; Ellerman and Buchner, 2007). While most economists favored auctioning, the European Union opted for almost completely free allocation for all sectors (industry and power sector) during phase I (2005-2007) and phase II (2008-2012); and maintained completely free (but declining at 1.74% per year) allocations¹ in phase III (2013-2020) for sectors “deemed to be exposed to carbon leakage”, and partly free for the rest of manufacturing industry (European Commission, 2009).

Indeed, the main argument used to justify free allocation has been the preservation of heavy industries’ competitiveness and the prevention of carbon leakage, which is a shift of emissions from carbon-constraint countries to less carbon-constrained countries induced by asymmetric carbon pricing (Dröge, 2009). However, economic theory suggests that free allocation, if independent from current production, is inefficient at preventing leakage in the short term and would only provide a disincentive to plant relocation (Wooders et al., 2009). In other words, in the short run free allocations would compensate firms for profitability losses without addressing market share losses and carbon leakage (Cook, 2011).

In addition to generous allocation caps, the economic downturn after 2008 led to a decrease in industrial production, which generated a large surplus of allowances in the market. These financial assets have mainly been held by cement and steel companies, because electricity demand has been much less

¹ Allocations in phase III are based on a product benchmark (the average of the 10% best performing installations: 766kg CO₂ per ton of clinker, the CO₂-intensive intermediate product required to produce cement), multiplied by a “cross sectoral correction factor” (0.9422 in 2013, declining by 1.74% per year), historical activity level (HAL, a formula leading approximately to pre-crisis level of production), and an “activity level correction factor” (reducing allocations by half or four if the plant is functioning below 50% or 25% of its HAL). Completely free allocations are then maintained though the overall cap of allowances is less generous (it has been reduced by 23% between 2012 and 2013) and declining. However because actual production is much lower than pre-crisis level, 2013 emissions were 20% lower than the cap.

impacted by the economic downturn.

Instead of suffering from financial losses, energy-intensive industries seem to have thrived from the scheme. Sandbag, a non-governmental organization, has estimated that the ten “carbon fat cats” have reaped billions of Euros in windfall profits (Pearson, 2010). However, their analysis, based on the European Union Transaction Log (EUTL) data, is based upon equivalence between allowances surplus and overallocation, without considering the fact that some allowances are obtained by reducing the carbon content of industrial products (Ellerman and Buchner, 2008). Indeed, apart from financial outcomes, an important question remains: whether the EU ETS has fulfilled its original purpose which was to trigger a transition towards low-carbon industry.

Studies assessing abatement in the manufacturing industry have obtained mixed results (Neuhoff et al., 2014). Zachman et al. (2011) find a significant reduction in carbon intensity for basic metals (whose emissions occur mostly in the steel sector) and non-metallic minerals (whose emissions occur mostly in the cement sector) between 2007 and 2008 compared to 2005-2006. Yet (Kettner et al., 2014) find very limited reduction in carbon intensity in the cement and lime sector, and attribute most of it to an increase in clinker imports – which implies carbon leakage. Moreover Egenhofer et al. (2011) find almost no decrease in the manufacturing industry’s carbon intensity in 2008, which seems to contradict Zachman et al. (2011) results.

In this paper, we propose to shed light on the questions of abatement and overallocation in the European cement industry, exploiting EUTL data, Eurostat international trade data, and the detailed and comprehensive Getting the Numbers Right (GNR) database from the Cement Sustainability Initiative (CSI). We perform an LMDI (Log Mean Divisia Index) decomposition (Ang, 2004) of emissions due to cement production in Europe. We measure the impact of seven effects on emissions variations, which correspond to different mitigation levers: activity, clinker trade, clinker share, alternative fuel use, thermal and electrical energy efficiency, and decarbonisation of electricity. This analysis allows us to identify the key drivers behind changes in aggregated carbon emissions, in the EU 27 as a whole and in six major European producers: Germany, France, Spain, the UK, Italy and Poland.

A distinction can be made between the first two effects (activity and clinker trade) that generate non-technological abatement and the others that generate technological abatement. Making assumptions on counterfactual scenarios, we estimate the technological abatement induced by the EU ETS and break down its main factors. Furthermore, our emissions decomposition model allows us to identify which part of the allowances surplus (allocations minus emissions) is due to technological performance and which is due to a change in activity or clinker outsourcing. We are then able to compute overallocation and “overallocation profits”.

We find that the EU ETS has induced a small but positive abatement of 26 Mtons of CO₂ (± 16 Mtons) from 2005 to 2012 (corresponding to a 2.2% \pm 1.3% decrease), mostly thanks to the reduction in the clinker-to-cement ratio. However we cannot rule out another explanation, i.e. the massive increase in

steam coal and petcoke prices in the 2000s (Cembureau, 2012). This aggregate figure hides important differences at national levels. Whereas technological abatement has been important in Germany ($5\% \pm 3\%$) and in the UK ($4\% \pm 3\%$), it has been small in France, and insignificant or negative in Spain, Italy and Poland. In addition, we estimate that the European cement industry has reaped 3.5 billion Euros of overallocation profits during phases I and II. Most of these profits come from the economic downturn that has reduced the demand for cement and thus for cement production, in turn generating a massive surplus of allowances.

The rest of the article is structured as follows. Section 2 details the cement manufacturing process and the mitigation options. Section 3 explains the emissions decomposition methodology. Section 4 applies this decomposition to changes in emissions in the European cement industry from 1990 to 2012. Section 5 is an assessment of technological abatement induced by the EU ETS and of overallocation profits. Section 6 concludes.

2. Mitigation options in the cement industry

2.1. Cement manufacture at a glance

Cement manufacture can be divided into two main steps: clinker manufacture, and blending and grinding clinker with other material to produce cement.

Clinker is produced by the calcination of limestone in a rotating kiln at 1450 degrees Celsius. Carbon dioxide is emitted in two ways. First, the chemical reaction releases carbon dioxide (ca. 538 kgCO₂ per ton of clinker²) which accounts for roughly two thirds of carbon emissions in clinker manufacture. The remaining CO₂ comes from the burning of fossil fuel to heat the kiln. The fuels used are mostly the cheapest ones, petcoke and coal (the use of gas and oil is precluded by cost, except in some locations where they are very cheap, which is not the case in the EU).

Raw material preparation, kiln operation, blending and grinding consume electricity which causes indirect emissions. However, nearly all carbon emissions (around 95%) in cement manufacture come from direct emissions in clinker manufacture.

To reduce emissions from cement production³, various options are thus available:

²The process CO₂ emission factor is generally considered as a fixed factor. However it is slightly variable mainly because of the ratio of calcium carbonate and magnesium carbonate in the limestone. When process emissions are actually measured, a narrow peak in the distribution can be observed at 538 kgCO₂ per ton of clinker (Ecofys et al. (2009) Figure 2). However, the factor used in the EU ETS Monitoring and Reporting of Greenhouse gas emissions (MRG) is only 523 kgCO₂ per ton of clinker, derived from IPCC methodology.

³If we consider cement *consumption* and not cement *production*, another option can be added: cement outsourcing. We performed the same analysis for cement consumption with a more complicated decomposition, adding cement trading. As the results barely changed (the cement trading effect represented less than 3 Mtons of CO₂ or 2% of emissions), for the sake of simplicity we only retained the analysis of cement production.

(i) *Reduction of cement production*, which may be due to reduced activity in the construction industry, to leaner structures or to the substitution of alternative materials to cement.

(ii) *Clinker substitution*. Since clinker manufacture is the most carbon intensive part of cement manufacture, partially substituting some other material for clinker is an efficient way to reduce emissions per ton of cement produced. The most common type of cement, ordinary Portland cement, is produced by mixing 95% of clinker and 5% of gypsum, but the clinker-to-cement ratio is lowered in blended cements.

(iii) *Clinker outsourcing*. This is a way to reduce emissions within a given geographical perimeter, but emissions then occur elsewhere, which causes carbon leakage.

(iv) *Alternative fuel use*, which releases less CO₂ for the same calorific value produced.

(v) *Energy efficiency*, which can be divided into two parts, *thermal* energy efficiency and *electrical* energy efficiency.

(vi) *Decarbonisation of the electricity*.

(vii) *Carbon capture and storage*.

(viii) *Innovative cements*, or carbon neutral cements based on totally different processes.

The next section details these options, which do not have the same status. Lever (i) is driven by cement demand and is not a direct choice made by cement companies. Levers (ii) to (v) are operational options used by cement companies (though lever (iii) does not reduce global emissions, it can be a rational choice for a company covered by an emissions trading scheme). Lever (vi) is beyond the scope of cement producers, and depends on electricity producers (which have an incentive to use it when there is a price on carbon). Abatement due to levers (i) to (vi) will be empirically assessed in this study. Levers (vii) and (viii) are in the research and development stage. Though promising, these options have not generated abatement yet.

The challenge of a non-global climate policy is to induce all these options (except (iii)) without generating clinker or cement imports, which would lead to carbon leakage.

2.2. Data sources

The work of this paper is based on the cross-referencing of three databases:

- the *Getting the Numbers Right* (GNR) database⁴ (WBCSD, 2009) developed by the Cement Sustainability Initiative (CSI), operating under the World Business Council on Sustainable Development (WBCSD).

⁴<http://wbcsdcement.org/GNR-2011/index.html>. Variables have names we will refer to for data sourcing. For example the clinker-to-cement ratio is variable 3213.

- the *European Union Transaction Log*⁵ (EUTL) which is the registry of the EU ETS, and provides allocations and verified emissions at the installation level.
- the *Eurostat* international trade database⁶ for clinker trading.

The GNR database covered 94% of European cement production in 2012 (only minor producers with small production volumes are excluded), which is remarkably high. Data are available⁷ for 1990, 2000, and 2005 to 2012. Data can be obtained at the EU 28 level and at the national level for big producers (so we have used data for Germany, France, Spain, the UK, Italy and Poland). Although the GNR database contains data on production and emissions, we use this database for its intensity (i.e. rate-based) indicators in the cement industry, for reasons related to coverage and methodology (see part 3.1). A performance indicator not included in GNR, the electricity emission factor, comes from the Enerdata database⁸.

The cement sector is a subsector of the cement/lime EUTL sector (47% of installations and 90% of allocations). We have collected plant-by-plant information on 276 cement plants with kilns covered by the EU ETS. Some characteristics of our cement EUTL database, which are in line with Table 1.2 in European Commission (2010) and Table 4 in Moya et al. (2010)⁹, are given in Table 1. The match between EUTL emissions and GNR gross direct emissions

⁵<http://ec.europa.eu/environment/ets/napMgt.do>

⁶<http://epp.eurostat.ec.europa.eu/newxtweb/setupdimselection.do>, EU Trade since 1988 by HS2, 4, 6 and CN8 dataset (extracted in February 2014). The code for clinker is 252310 ("cement clinkers").

⁷Due to confidentiality reasons, there is a one year gap between data collection and publication. The latest data available (2012) were published in August 2014.

⁸<http://www.enerdata.net/enerdatauk/knowledge/subscriptions/database/energy-market-data-and-co2-emissions-data.php>

⁹Their list contains 268 installations in 2006 at the EU 27 level (compared to 270 for us (Norway has two cement plants and Croatia four)). There are some discrepancies for France (33 instead of 30 for us), Germany (38 instead of 43), Italy (59 instead of 52), and some other countries (1 plant difference). In Germany, geolocalization of plants revealed that three plants had two EU ETS installations and 1 had three. Our list was cross-checked with the Cemnet database (<http://www.cemnet.com/GCR/>), Sandbag database, and public reports of major cement companies.

is good but not perfect¹⁰. In addition, we use the Sandbag database¹¹ for offset credits utilization at the installation level.

Whereas total imports and exports are directly available in the Eurostat international trade database at the EU 27 level, they have to be computed from country-pairs raw data at the national level. Also, some corrections needed to be made to take into account the changing geographical perimeter of the EU ETS. Because they are absent from Eurostat, we used the Comtrade database¹² for net imports in Norway, Iceland, and the EU 27 before 1999.

2.3. *Clinker substitution*

Reducing the clinker-to-cement ratio is a very efficient abatement option since most of the carbon emissions are produced during clinker manufacturing. The most-used clinker-substituting materials are fly ash (a residue from coal-fired power stations), ground blast furnace slag (a by-product of the steel industry), pozzolana (a volcanic ash) and limestone. Blast furnace cement offers the highest potential for clinker reduction with a clinker-to-cement ratio of 5-64%, compared to pozzolanic cement (45-89%) and fly ash cement (65-94%) (Moya et al., 2010).

Two barriers are impeding the deployment of blended cements. The first is the regional availability of the clinker substitutes, or their price (since these products have low value per ton, transportation costs are high). The phasing out of coal-fired plants triggered by climate policy will make fly ash scarcer. Ground blast depends on iron and steel production, and pozzolanas are present only in certain volcanic regions (mainly Italy). Second, the physical properties of these alternative cements such as strength, colour and workability, and their acceptance by construction contractors, constitute another barrier to their implementation (IEA, 2009).

Figure 1 displays the clinker-to-cement ratio in 1990, 2000 and from 2005 to 2012 for the European Union (with 28 member states) and the six biggest cement producers in Europe: Germany, France, Spain, Italy, the United Kingdom and Poland. The average EU 28 clinker-to-cement ratio decreased from 78% in 1990 to 73% in 2012. The UK is the country for which the clinker-to-cement ratio

¹⁰GNR emissions are higher in the United Kingdom, Germany and Poland, (3% on average respectively for all) whereas they are lower Italy and at the EU 27 level (6% and 2% respectively). France and Spain are perfect matches. Besides data-capture errors, differences in emissions can occur for different reasons. First, there is a mismatch in installations covered. GNR contains more plants because it includes grinding or blending plants, but some plants with kilns are not covered, so emissions at the national level have to be extrapolated. Second, accounting methodologies are different. Process emissions are measured in GNR (there is a peak in the distribution at 538 kgCO₂ per ton of clinker see figure 2 in (Ecofys et al., 2009)) whereas a default factor derived from IPCC methodology of 523 kgCO₂ per ton of clinker is used in the EU ETS. Non-kiln fuels are not reported in some countries for the EU ETS but are (partially) reported in GNR. The carbon content of alternative fuels is also accounted for differently.

¹¹<http://www.sandbag.org.uk/data/>

¹²<https://wits.worldbank.org/WITS/WITS/Restricted/Login.aspx>

Table 1: Cement EUTL database. Country level (Sandbag database used for offset credits)

Region	Number of plants		Annual Allocation (MtonsCO ₂ /year)		Annual Emissions (MtonsCO ₂ /year)		Offset credits used (phase II)	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II	Total	% cap
EU ETS	254	262	158.3	178.6	153.8	131.1	88.6	10.0%
Germany	47	40	23.5	21.0	20.9	19.6	22.2	21.1%
France	30	30	14.1	15.3	14.3	12.5	10.1	13.3%
Spain	35	36	27.5	29.2	26.8	17.6	10.7	7.4%
United Kingdom	13	15	5.6	10.1	5.7	6.3	3.3	6.7%
Italy	52	54	26.2	28.0	27.8	21.1	10.0	7.2%
Poland	11	11	10.8	11.0	9.7	10.0	4.6	8.4%
Subtotal	189	187	108.2	115.0	105.8	87.5	61.2	10.6%
	74%	71%	68%	64%	69%	66%	69%	
Austria	9	9	2.8	2.7	3.0	2.6	1.2	9.2%
Greece	8	8	11.1	10.8	10.7	6.6	3.3	6.2%
Romania	7	7	2.3	9.3	2.2	5.1	4.3	9.3%
Czech Republic	6	5	3.0	2.8	2.9	2.5	1.4	10.0%
Portugal	6	6	6.8	6.7	6.6	5.1	3.3	10.0%
Belgium	5	5	5.5	5.0	5.0	4.3	1.0	4.0%
Bulgaria	NP	5	NP	3.6	NP	1.9	2.1	11.5%
Hungary	4	5	2.4	2.2	2.1	1.4	0.9	8.4%
Ireland	4	4	3.6	4.0	3.8	2.1	2.2	11.0%
Slovakia	4	4	2.3	2.7	2.2	1.9	0.9	6.7%
Sweden	3	3	2.2	2.5	2.2	2.2	1.2	9.3%
Cyprus	NP	2	NP	1.7	NP	0.9	0.8	9.3%
Finland	2	2	1.1	1.3	1.0	0.8	0.5	8.0%
Netherlands	1	1	0.8	0.7	0.6	0.5	0.3	8.8%
Slovenia	2	2	0.8	0.7	0.8	0.6	0.4	12.1%
Denmark	1	1	2.8	2.6	2.7	1.7	0.8	6.5%
Estonia	1	1	0.9	0.8	0.9	0.8	0.2	4.1%
Latvia	1	2	0.3	0.9	0.3	0.6	0.4	8.9%
Lithuania	1	1	1.1	1.0	1.0	0.7	1.0	20.0%
Luxembourg	1	1	0.8	0.7	0.7	0.6	0.4	10.0%
Norway	NP	2	NP	1.3	NP	1.2	0.8	12.7%

NP is for Non Participating

Note:

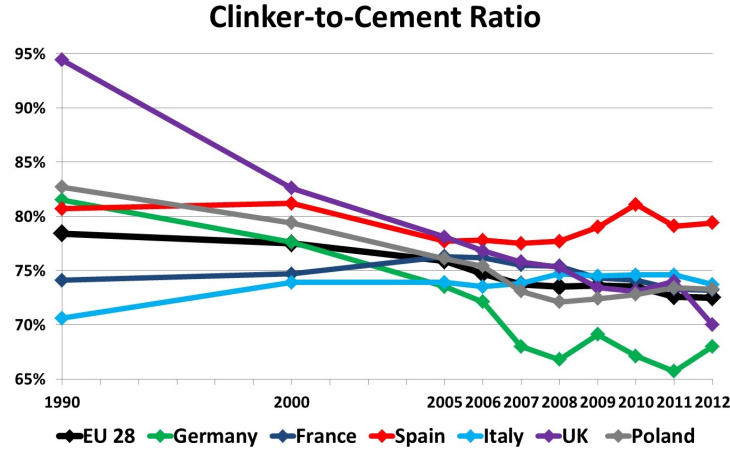


Figure 1: Clinker-to-cement ratio for the EU 28 and main European countries. Source: WBCSD GNR Database, variable 3213

has decreased the most dramatically, from 95% in 1990 to 70% in 2012. In 2012 Germany was the country with the lowest clinker-to-cement ratio, 68%, whereas Spain had the highest, 79%.

2.4. Clinker outsourcing

Clinker outsourcing is a drastic method to reduce carbon emissions within a given geographical perimeter, but it does not in general reduce emissions on a global scale (carbon intensity is approximately the same in Europe and abroad and this adds emissions due to transportation). The increase in emissions abroad due to a regional climate policy is called carbon leakage (Reinaud, 2008). In the EU ETS, free allocation of allowances was presented as a way to mitigate the risk of leakage.

The purpose of this paper is to assess the actual emissions reductions in the cement industry, and not to provide a technology roadmap. Therefore just because clinker outsourcing is an undesirable option does not mean that it should not be considered in this context. Under the EU ETS, it can be profitable since, provided that a certain level of activity is maintained, the operator of an installation keeps receiving free allowances that can be sold on the market. However, logistical difficulties, high transportation costs and export barriers make clinker outsourcing less appealing than it appears. Clinker trading primarily occurs in the case of over- or under-capacity (Cook, 2011). Geography plays an important role: high road transport costs exclude inland producers from international trade (Ponssard and Walker, 2008).

Figure 2 shows clinker net imports (imports minus exports) divided by clinker production. The EU 27 switched from being a clinker importer to being a clinker exporter in 2009. We can see that clinker is a poorly traded commodity: since 1990 net extra-EU27 imports or exports have never been more than

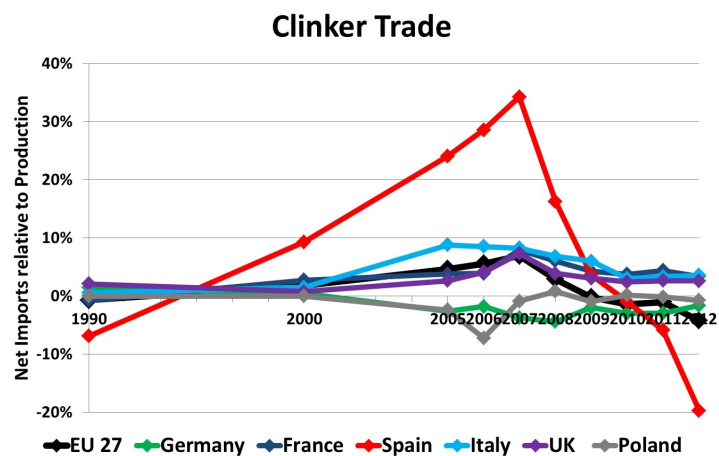


Figure 2: Net imports (imports minus exports) of clinker relative to local clinker production. Sources: Eurostat for net imports, EUTL and WBCSD GNR Database for production

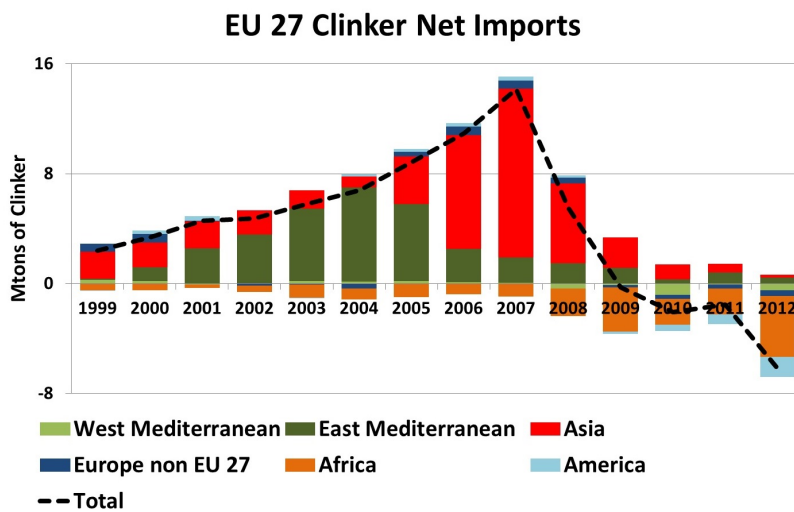


Figure 3: Origin of the EU 27 net imports. West Mediterranean comprises Morocco, Algeria, Tunisia and Libya. Source: Eurostat

7% of its production. Imports came from Asia (mostly China and Thailand) and the East Mediterranean region especially between 2001 and 2005 (mainly Turkey and Egypt), and since 2010 European clinker has mainly been exported to the Gulf of Guinea and Brazil (see Figure 3). The European country with the most remarkable trajectory is Spain, which turned into a massive clinker exporter (20% of its production in 2012) after being a massive importer (up to 34% of its production in 2007). This swing can be explained by the boom and burst of the construction bubble. Further, most of the surge of clinker exports in 2012 compared to 2011 can be attributed to phase III allocation rules¹³ (Branger et al., 2014).

2.5. *Alternative fuel use*

The conventional fossil fuels used in clinker manufacture, coal and petcoke, have a high carbon intensity. Replacing these fuels by alternative, less carbon intensive fuels generates abatement. The proportion of alternative fuel used in thermal energy production has increased steadily in the European Union. Fossil and mixed wastes¹⁴, which are generally less carbon-intensive than coal or petcoke, represented 2% of thermal energy in 1990, 11% in 2005 and 25% in 2012¹⁵. Biomass represented¹⁶ 0.2% of thermal energy in 1990, 4% in 2005 and 11% in 2012¹⁷. Most cement companies receive a fee for the burning of waste as part of a waste management strategy to reduce incineration and landfilling; so using alternative fuel may be financially advantageous regardless of the carbon price.

The carbon intensity of the fuel mix (shown in Figure 4) has decreased from 94 kgCO₂/GJ in 1990¹⁸ to 80kgCO₂/GJ in 2012. In 2012, Germany had the lowest carbon intensity of the fuel mix by far (71 kgCO₂/GJ), while Italy had the highest (89 kgCO₂/GJ).

Much higher substitution rates are possible than the currently-used mixes but several factors limit the potential of alternative fuel use. First, the calorific value of most organic material is relatively low, and treatment of side products (such as chlorine) is sometimes needed (European Commission, 2010). Second, the availability of waste is dependent on the local waste legislation and collection network as well as nearby industrial activity (IEA, 2009). Third, a higher CO₂ price may increase the global demand for biomass, for which cement companies

¹³ Allowances are cut by half if the plant produces less than half of its historical activity level. This encouraged plants to overproduce to reach the threshold. Excess clinker production has then been exported or blended in cement, increasing the clinker-to-cement ratio.

¹⁴ Mostly plastics, mixed industrial waste, and tyres in 2012 (respectively 43%, 20% and 17% (source: GNR database, variable 3211detail).

¹⁵ GNR database, variable 3211a.

¹⁶ Mostly animal meal and dried sewage sludge: respectively 49% and 20% (source: GNR database, variable 3211detail).

¹⁷ GNR database, variable 3211a.

¹⁸ For this value only, we took the average of European country values weighted by their cement production. Indeed, the original GNR value (91 kgCO₂/GJ) was lower than all values corresponding to individual European countries .

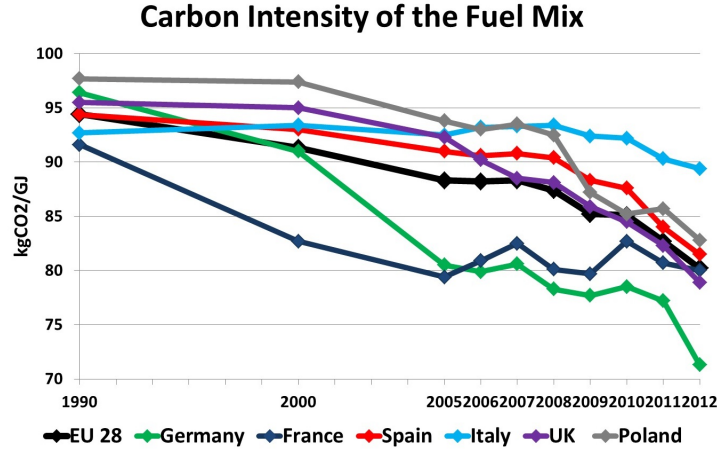


Figure 4: Carbon intensity of the fuel mix (in kgCO₂/GJ) for the EU 28 and main European countries. Source: WBCSD GNR Database, variable 3221

compete with heat and electricity producers. This would increase its price and make it less appealing as a fuel substitute for the cement industry. Finally, social acceptance is of huge relevance as incineration is often viewed with great suspicion by surrounding inhabitants.

2.6. Thermal and electrical energy efficiency

Cement manufacture requires both thermal energy for heating the clinker kiln and electrical energy (about 10% of total energy needed) mostly for kiln operation, grinding (preparing raw materials) and blending (mixing clinker with additives). The proportion of total electrical energy used for these steps is respectively 25%, 33% and 30% according to Schneider et al. (2011).

New kilns using raw material in powder form (dry production route) are much more energy efficient than old kilns using raw material in a slurry (wet production route) since less heat is needed to dry the raw material¹⁹ (3-4 GJ per ton of clinker instead of 5-6 GJ per ton of clinker in European Commission (2010)). In modern kilns, part of the heat of the exhaust gases from the kiln is recovered to pre-heat the raw material (pre-heaters) (Pardo et al., 2011). The state-of-the art technology is the dry process kiln with pre-heating and pre-calcining, which requires approximately 3 GJ per ton of clinker and accounts for 46% of European clinker production in 2012 (compared to 23% in 1990²⁰).

In addition to kiln technology, kiln capacity also influences energy efficiency. Bigger kilns have lower heat losses per unit of clinker produced and are therefore

¹⁹It is common in the literature to distinguish four routes for cement manufacture: dry, semi-dry, semi-wet and wet (GNR).

²⁰Source: GNR database, variable Percent315.

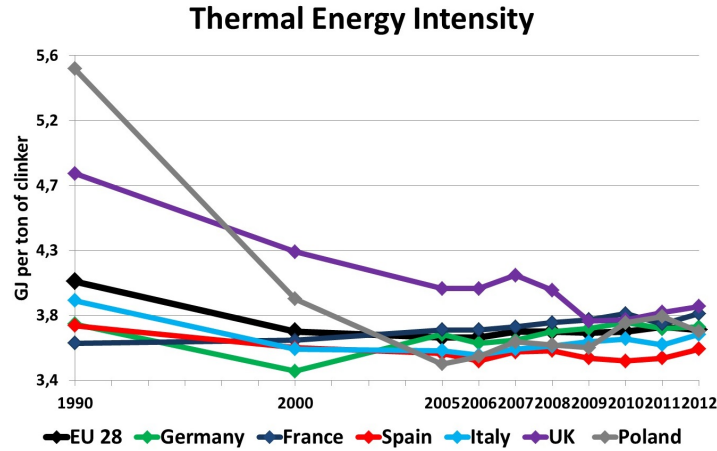


Figure 5: Thermal energy intensity in GJ per ton of clinker for the EU 28 and main European countries. Source: WBCSD GNR Database, variable 329.

more energy-efficient. Finally, for a given installation, the way the machinery is operated (minimizing kiln shutdowns and operating near to nominal capacity) can make a significant difference (about 0.15-0.3 GJ per ton of clinker according to Hoenig and Twigg (2009)).

Cement producers benefit directly from energy efficiency through lower energy costs, which represent roughly a third of production costs (Bolscher et al., 2013; Pardo et al., 2011). Generally, new manufacturing plants are equipped with the best available technology, but the upgrading of old facilities is a slow process. Moya et al. (2011) find that the observed rate of retrofitting in the cement industry is much lower than the theoretical rate derived from the number of feasible improvements with low payback periods, revealing an “energy efficiency gap” (Jaffe and Stavins, 1994) or “energy efficiency paradox” (deCanio, 1998).

Figures 5 and 6 show the thermal energy intensity and the electrical energy intensity, respectively in GJ per ton of clinker and in kWh per ton of cement. The thermal energy intensity in the EU 28 decreased from 4.1 GJ per ton of clinker in 1990 to 3.7 GJ per ton of clinker in 2005 then stabilized. The electrical energy intensity in the EU 28, after decreasing from 114 kWh per ton of cement in 1990 to 108 kWh per ton of cement in 2006 increased to 116 kWh per ton of cement in 2012. The most noticeable change comes from Spain where average electricity intensity soared from 98 kWh/ton of cement in 2006 to 150kWh per ton of cement in 2012, probably due to the decrease in production which led to the use of machinery operating well below nominal capacity²¹.

²¹Spanish cement production was divided by three in the same period. To understand such a dramatic increase, whereas in the same time thermal energy intensity has not evolved, two

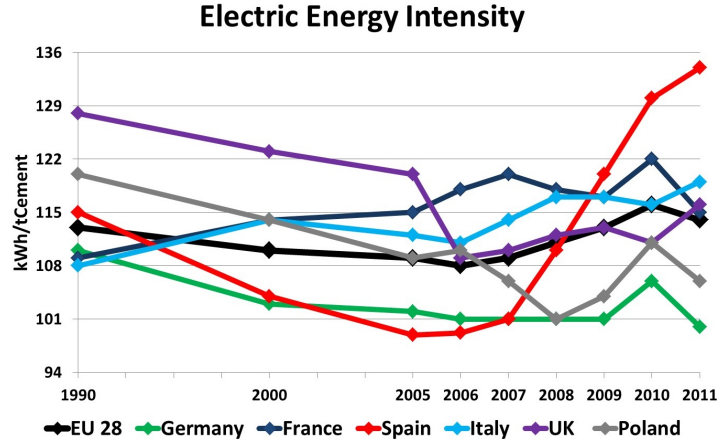


Figure 6: Electrical energy intensity in kWh per ton of cement for the EU 28 and main European countries. Source: WBCSD GNR Database, variable 3212.

There are no breakthrough technologies in sight that would allow a significant decrease in kiln energy consumption (European Commission, 2010), so the potential for abatement is small. In addition, the other abatement drivers can be negatively correlated to energy efficiency. Clinker substitutes (especially blast furnace slag) generally require more energy for grinding, and alternative fuels may provide less calorific power or may need more energy to treat by-products. Moreover, more stringent environmental requirements (dust and gas treatment), increased cement performance (necessitating finer grinding) and kiln improvements such as pre-heaters and pre-calciners have led to higher power consumption (Hoenig and Twigg, 2009). These reasons could explain why energy efficiency has stabilized or deteriorated in recent years.

2.7. Decarbonisation of electricity

For the sake of simplicity in this study we consider that all the electricity consumed comes from the grid²². In this context, this mitigation option does not depend on the cement industry but on electricity producers. Indirect electricity emissions represent around 6% of total emissions in the cement industry. Under the EU ETS framework, these emissions are attributed to electricity producers and not to cement manufacturers. Cement companies do not receive allowances

explanations can be proposed. First, contrary to kiln fuel which is fully variable, there is a higher share of “non-productive” electric energy (such as lighting, heating, water pumping and compressed air). Second, some plants have several kilns, so production can be redirected to the most efficient ones only. Conversely, most plants have only one grinder.

²²The number of plants recovering heat for power generation is unknown (Matthes et al., 2008). Self-generation of power is more frequent in countries where electricity supply is not reliable (VDZ (German Cement Association), 2013).

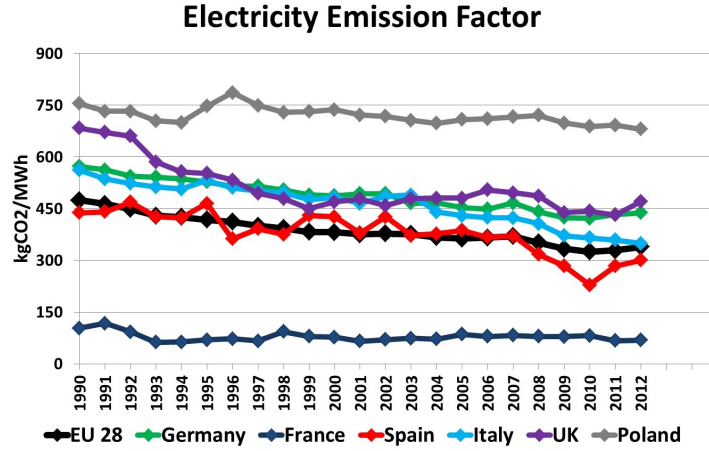


Figure 7: Electricity emission factor (in kgCO₂/MWh) for the EU 27 and main European countries. Source: Enerdata database

for these emissions and neither do they have to surrender allowances for them. However, they may face indirect costs through the rise in electricity prices due to the passing-through of allowance prices. Though small, this abatement option still has the potential to decrease total emissions in the cement industry.

Figure 7 shows the changes in the electricity emissions factor (in kgCO₂/MWh). It has globally decreased in all European countries, and the EU 27 average dropped from 474 kgCO₂/MWh in 1990 to 339 kg CO₂/MWh. In 2012, the country with the highest electricity emissions factor was Poland with 680 kgCO₂/MWh (because of the predominance of coal power) and the country with the lowest was France with 69 kgCO₂/MWh (because of the high proportion of nuclear and hydro-electric power).

2.8. Carbon capture and storage

Most carbon emissions from cement manufacturing are process emissions due to the chemical reaction during limestone calcination. The only way to avoid these emissions (apart from alternative cements based on different chemical processes) would be carbon capture and storage (CCS) using post-combustion technologies. Emissions due to burning of fossil fuels could also be managed with CCS technologies. A promising option in this direction is oxyfuel technology where air is replaced by oxygen in cement kilns to produce a pure CO₂ stream that is easier to handle (Barker et al., 2009; Li et al., 2013).

R&D in CCS is active but these potentially promising technologies are far from being operational at the industrial scale (Moya et al., 2010). A high carbon price (estimations vary but an order of magnitude is 50€/tonCO₂) would be necessary to trigger investments in this medium-term option. Furthermore, CCS technologies are energy-intensive and would increase power consumption significantly (by 50% to 120% at plant level according to Hoenig and Twigg

(2009)). Finally, their large-scale development would necessitate a complete CCS system, including transport infrastructure, access to storage sites, a legal framework for CO₂ transportation, monitoring and verification, and therefore political and social acceptance (IEA, 2009).

2.9. Innovative cements

Several low-carbon or even carbon-negative cements are at the development stage, such as Novacem (based on magnesium silicates rather than limestone), Calera or Geopolymer (Schneider et al., 2011). Providing they prove their economic viability and gain customer acceptance (which is extremely challenging in itself), replacing existing facilities would require considerable time and investment.

2.10. Cement substitution in construction

This option, aimed at reducing the overall quantity of cement produced, depends on architects and construction companies. Like decarbonisation of electricity, it depends on other stakeholders. Whereas cement companies are indifferent to the carbon content of electricity (for a given electricity price), a reduction in quantities of cement used in construction is at first sight against the interests of the cement industry.

Reducing quantities of cement used in construction would be possible through alternative materials and/or leaner structures. Wood would be the most natural alternative construction material to cement, provided that its large-scale availability could be assured.

3. Methodology

Thus far, we have presented the emission abatement options qualitatively or on the basis of simple indicators. Quantifying their respective contribution in the evolution of cement CO₂ emissions requires a decomposition method, which we describe in the next section.

3.1. Decomposition of carbon emissions due to cement production

In the rest of this section, C stands for emissions, Q for quantities and E for energy consumption. The definition of all the variables used can be found in Table 2.

We distinguish $Q_{clinker,t}^{PROD}$ which is the quantity of clinker *produced* at year t and $Q_{clinker,t}^{NET}$ which is the quantity of clinker actually *used* for cement manufacture. The difference between the two comes from international trade (we neglect stock variations):

$$Q_{clinker,t}^{NET} = Q_{clinker,t}^{PROD} + NI_{clinker,t} \quad (1)$$

Table 2: Definition of variables

Variable	Definition	Unit
t	Year. All variables (except CEF_{pro}) are yearly	
C_t	Total carbon emissions in the cement manufacturing process	MtonCO ₂
$C_{EUTL,t}$	Direct carbon emissions in the cement manufacturing process	MtonCO ₂
$C_{F,t}$	Fuel-related emissions	MtonCO ₂
$C_{P,t}$	Process emissions	MtonCO ₂
$C_{E,t}$	Indirect carbon emissions due to electricity consumption	MtonCO ₂
$Q_{clinker,t}^{NET}$	Quantity of cement manufactured	Mtons
$Q_{clinker,t}^{PROD}$	Quantity of clinker manufactured	Mtons
$NI_{clinker,t}$	Net imports (imports minus exports) of clinker	Mtons
$Q_{cement,t}$	Quantity of clinker used to manufacture cement	Mtons
H_t	Clinker home production ratio ($= \frac{Q_{clinker,t}^{NET}}{Q_{clinker,t}^{PROD}}$)	None
R_t	Clinker-to-cement ratio	None
$I_{T,t}$	Thermal energy intensity	GJ per ton of clinker
$I_{El,t}$	Electrical energy intensity	MWh per ton of cement
$CEF_{F,t}$	Carbon intensity of the fuel mix	tCO ₂ /GJ
CEF_{pro}	Carbon emission factor of limestone calcination	tCO ₂ per ton of clinker
$CEF_{elec,t}$	Electricity emission factor	tCO ₂ /MWh
A_t	Allocation cap	MtCO ₂
C_eCI_t	Cement carbon intensity	tCO ₂ per ton of cement
C_kCI_t	Clinker carbon intensity	tCO ₂ per ton of clinker

Note: Some variable units for LMDI analysis differ from the units used in section 2.1

$NI_{clinker,t}$ being net imports of clinker. We split emissions into three categories: emissions due to fuel burning (subscript F), process emissions (subscript P) and indirect emissions due to electricity consumption (subscript E):

$$C_t = C_{F,t} + C_{P,t} + C_{E,t} \quad (2)$$

Only direct emissions are accounted for in the EU ETS.

$$C_{EUTL,t} = C_{F,t} + C_{P,t} \quad (3)$$

First, emissions due to fuel burning, $C_{F,t}$, can be decomposed as follows:

$$\begin{aligned} C_{F,t} &= Q_{cement,t} \frac{Q_{clinker,t}^{NET}}{Q_{cement,t}} \frac{Q_{clinker,t}^{PROD}}{Q_{clinker,t}^{NET}} \frac{E_{T,clinker,t}}{Q_{clinker,t}^{PROD}} \frac{C_{F,t}}{E_{T,clinker,t}} \\ &= Q_{cement,t} \times R_t \times H_t \times I_{T,t} \times CEF_{F,t} \end{aligned} \quad (4)$$

where $E_{T,clinker,t}$ is the thermal energy used, R_t the clinker-to-cement ratio, H_t is the clinker home production ratio ($H_t > 1$ if more clinker is produced than used, or, put another way, if net imports are negative), $I_{T,t}$ is the thermal energy intensity (in GJ per ton of clinker) and $CEF_{F,t}$ is the carbon intensity of the fuel mix (in tCO₂/GJ).

The formulation for process emissions $C_{P,t}$ is:

$$\begin{aligned} C_{P,t} &= Q_{cement,t} \frac{Q_{clinker,t}^{NET}}{Q_{cement,t}} \frac{Q_{clinker,t}^{PROD}}{Q_{clinker,t}^{NET}} \frac{C_{P,t}}{Q_{clinker,t}^{PROD}} \\ &= Q_{cement,t} \times R_t \times H_t \times CEF_{pro} \end{aligned} \quad (5)$$

where CEF_{pro} is the CO₂ emission factor for the calcination of limestone which is considered here time invariant, absent any information on its evolution.

The formulation for $C_{E,t}$ is:

$$\begin{aligned} C_{E,t} &= Q_{cement,t} \frac{E_{E,t}}{Q_{cement,t}} \frac{C_{E,t}}{E_{E,t}} \\ &= Q_{cement,t} \times I_{El,t} \times CEF_{elec,t} \end{aligned} \quad (6)$$

where $E_{T,clinker,t}$ is the electrical energy used, $I_{El,t}$ is the electrical energy intensity of production (in MWh per ton of cement) and $CEF_{elec,t}$ is the electricity emission factor (in tCO₂/MWh).

Total emissions of cement manufacturing are then

$$C_t = Q_{cement,t} \times (R_t \times H_t \times (CEF_{pro} + I_{T,t} \times CEF_{F,t}) + I_{El,t} \times CEF_{elec,t}) \quad (7)$$

Abatement levers are more visible in this formula that is composed only of positive terms: besides reducing activity (reducing $Q_{cement,t}$) or outsourcing

clinker (reducing H_t), technological abatement options are reducing R_t (clinker substitution), $CEF_{F,t}$ (alternative fuel use), $I_{T,t}$ and $I_{El,t}$ (thermal and electrical energy efficiency), and reducing $CEF_{elec,t}$ (decarbonisation of electricity).

For the data, we have taken directly from GNR the intensity variables R_t (variable 3213), $CEF_{F,t}$ (variable 3221), $I_{T,t}$ (variable 329) and $I_{El,t}$ (variable 3212). These data are given at the EU 28 level (whereas we focus on the EU 27 level) but the error is low since they are intensity variables, and Croatia's cement production accounts for less than 2% of EU 28 cement production (Mikulčić et al., 2013). $CEF_{elec,t}$ comes from the Enerdata database and CEF_{pro} from Ecofys et al. (2009) (we take, unless explicitly mentioned otherwise, the measured value from the GNR database, 538 kgCO₂ per ton of clinker, rather than the default factor of 523 kgCO₂ per ton of clinker derived from the IPCC methodology used in the EU ETS).

H_t and $Q_{cement,t}$ are obtained indirectly by computation. The quantity of clinker produced is obtained by dividing EUTL emissions²³ by the clinker carbon intensity (using the EU ETS value of CEF_{pro}):

$$Q_{clinker,t}^{PROD} = \frac{CEUTL,t}{CEF_{pro} + I_{T,t} \times CEF_{F,t}} = \frac{CEUTL,t}{C_k CI_t} \quad (8)$$

where $C_k CI_t$ is the clinker carbon intensity. Then H_t is given by:

$$H_t = \frac{Q_{clinker,t}^{PROD}}{Q_{clinker,t}^{PROD} + NI_{clinker,t}} \quad (9)$$

where $NI_{clinker,t}$ comes from the Eurostat international trade database. $Q_{cement,t}$ is obtained by:

$$Q_{cement,t} = \frac{Q_{clinker,t}^{PROD} + NI_{clinker,t}}{R_t} \quad (10)$$

Computing indirectly clinker and cement production (whereas they are available in the GNR database) is a modelling choice. Indeed, equation (7) is a perfect accounting equality, but in practice there are always mismatches due to data inaccuracy, and so one variable has to be computed through the equation (instead of coming from data source). The choice of which variable to compute is determined by the quality of the data and the use of the decomposition. In our case we have a choice between using GNR data on clinker and cement production and compute emissions, or using EUTL emissions data for direct emissions and compute clinker and cement production. We chose the second option for two

²³Sometimes EUTL emissions do not exist (before 2005) or are not reliable: for the EU 27 in phase I, because some countries were not covered, and for the UK in phase I, because of the opt-out condition, some plants were not part of the scheme. In these cases we use GNR direct emissions, corrected by a factor to take into account the discrepancy between GNR and EUTL emissions. The factor is 2005-2010 EUTL emissions divided by 2005-2010 GNR emissions (we take the period 2008-2010 for the EU 27 and the UK).

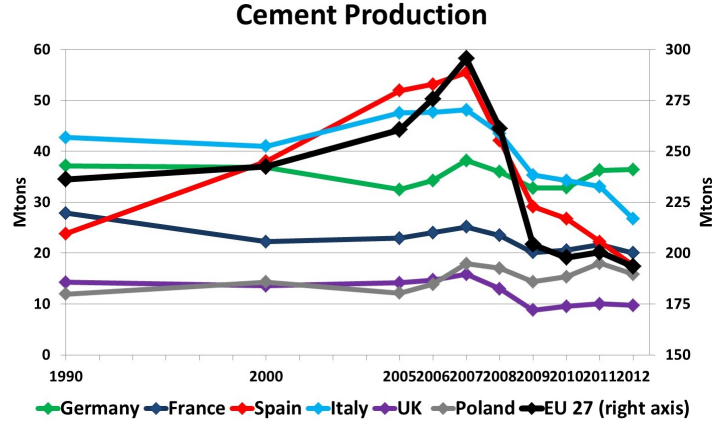


Figure 8: Cement production in million tons for the EU 27 (right vertical axis) and the main European countries (left vertical axis). Source: Computation from WBCSD GNR Database, EUTL database and Eurostat International Database

reasons. First, it allows finding EUTL emissions after recalculation for direct emissions, and EUTL emissions are extremely reliable: the coverage is 100%, and it comes from a compulsory policy rather than a voluntary program. GNR coverage is good but not perfect (some clinker plants are missing and grinding plants using imported clinker may not be covered). As an example, in Spain in 2007 (the country-year with the highest clinker importation), the GNR database gives a production of 46.8 Mt of cement, whereas our own computation (with 11.0 Mt of clinker net imports) gives 55.4 Mt, which are closer to the official figure of the Spanish cement association: 54.7 Mt (Oficemen, 2013). Second, it allows decomposing the *exact* allowances surplus and not an approximation of it (see section 5.3). Anyway, the difference between computed clinker production and reported GNR data at the EU level is small and stable over time²⁴. So, given the order of magnitude of changes in the overall production, and because we are more interested in relative changes than absolute values, using one or the other would have hardly any impact on results of section 4.

3.2. LMDI method

Index decomposition analysis (IDA) has been widely used in studies dealing with energy consumption since the 1980s and carbon emissions since the 1990s.

²⁴Computed production is higher than GNR data by about 3-4% for clinker and 6-7% for cement. Two reasons could explain the difference: the coverage (as coverage is around 95%, GNR underestimate cement production by about 5%) and white clinker. White clinker, which represents a tiny fraction of clinker production, is more carbon-intensive (by around 30%) than grey clinker. GNR intensity variables mostly concern grey clinker only, whereas EUTL emissions do not distinguish grey and white clinker. This introduces an upward bias in computed production. The higher the proportion of white clinker, the higher the bias; and the bias is stable in time if the proportion of white clinker production remains stable.

Ang (2004) compares different IDA methods and concludes that the Logarithm Mean Divisia Index (LMDI) is to be preferred. A comprehensive literature survey reviewing 80 IDA studies dealing with emissions decomposition is given in Xu and Ang (2013), and shows that the LMDI became the standard method after 2007.

The general formulation of LMDI (see Ang (2005)) is the following. When emissions can be decomposed as $C_t = X^1 \times X^2 \times \dots \times X^n$, the variation of emissions $\Delta^{tot} = C_T - C_0$ can be decomposed as $\Delta^{tot} = \Delta^1 + \Delta^2 + \dots + \Delta^n$, with

$$\Delta^k = \frac{C_T - C_0}{\ln(C_T) - \ln(C_0)} \times \ln\left(\frac{X_T^k}{X_0^k}\right) \quad (11)$$

LMDI decomposition is mostly used to study the difference in emissions between two dates for a given country, but the mathematical formulation also works for difference in emissions for two countries at a given date, or (as we will see later), for difference in emissions for a given country between a real and a counterfactual or reference scenario.

Among the 34 studies since 2002 using LMDI decomposition analysis in Xu and Ang (2013) literature review, the majority (14) are economy-wide and only seven focus on industry. But except for Sheinbaum et al. (2010) (iron and steel in Mexico), they are not sector-specific but deal with industry or the manufacturing sector as a whole; in China (Liu and Ang, 2007; Chen, 2011), Shanghai (Zhao et al., 2010), Chongqin (Yang and Chen, 2010), the UK (Hammond and Norman, 2012) or Thailand (Bhattacharyya and Ussanarassamee, 2004). For sector specific studies (not using the LMDI method), one can cite two international comparisons for cement (Kim and Worrell, 2002a) and steel (Kim and Worrell, 2002b) and a study of the iron and steel industry in Mexico (Ozawa, 2002).

The study closest to ours is Xu et al. (2012), which was not cited in Xu and Ang (2013), focusing on the cement industry in China. They give a decomposition per kiln type, allowing the energy efficiency effect to be separated into a structural effect (change of kiln type) and a kiln efficiency effect²⁵. However they do not consider clinker trade in their decomposition, which is arguably of little importance for China, but matters for Europe.

Expanding equation (7) leads to the following decomposition:

$$\begin{aligned} \Delta^{tot} &= C_T - C_0 \\ &= \Delta^{act-F} + \Delta^{sha-F} + \Delta^{tra-F} + \Delta^{fmix} + \Delta^{eff-F} \\ &\quad + \Delta^{act-P} + \Delta^{sha-P} + \Delta^{tra-P} \\ &\quad + \Delta^{act-E} + \Delta^{eff-E} + \Delta^{Celec} \\ &= \Delta^{act} + \Delta^{sha} + \Delta^{tra} + \Delta^{fmix} + \Delta^{eff-F} + \Delta^{eff-E} + \Delta^{Celec} \end{aligned} \quad (12)$$

²⁵Kiln energy intensity over time per kiln type was not available in the GNR database, so we opted for a simpler decomposition.

performing the appropriate groupings: $\Delta^{act} = \Delta^{act-F} + \Delta^{act-P} + \Delta^{act-E}$, $\Delta^{tra} = \Delta^{tra-F} + \Delta^{tra-P}$ and $\Delta^{sha} = \Delta^{sha-F} + \Delta^{sha-P}$.

The precise formulas are all given in the Appendix.

There are then seven factors in the decomposition:

- The *activity effect* (Δ^{act}): impact of total cement production on emissions variations. It corresponds to lever (i) in part 2.1
- The *clinker trade effect* (Δ^{tra}): impact of the clinker trade on emissions variations. It corresponds to lever (iii) in part 2.1.
- The *clinker share effect* (Δ^{sha}): impact of clinker substitution on emissions variations. It corresponds to lever (ii) in part 2.1.
- The *fuel mix effect* (Δ^{fmix}): impact of the use of alternative fuel on emissions variations. It corresponds to lever (iv) in part 2.1.
- The *thermal and electrical energy efficiency effect* (Δ^{eff-F} and Δ^{eff-E}): impact of thermal and electrical energy efficiency. They correspond to lever (v) in part 2.1.
- The *electricity carbon emissions factor effect* (Δ^{Celec}): impact of the carbon emissions factor on emissions variations. It corresponds to lever (vi) in part 2.1.

One can distinguish the first two effects (activity and clinker trade) which are “non-technological” abatement options from the others that are technological abatement options.

4. Changes in carbon emissions in the European cement industry

4.1. EU 27

Figure 9 shows changes in carbon emissions over time compared to their 1990 level alongside the LMDI decomposition analysis explained above ²⁶.

Emissions in the cement industry first decreased in the 1990s and the beginning of the 2000s (-4.7% from 1990 to 2005) then increased sharply to exceed the 1990 level (+3.6% in 2007 compared to 1990). The economic recession led to a sharp decrease in emissions: in 2009 they were 25.1% lower than in 1990 (which corresponds to a 29.1% reduction in emissions in two years) and kept decreasing slowly afterwards.

The LMDI analysis allows us to highlight the fact that most of the emissions variations in the EU 27 are attributable to the activity effect: cement emissions have increased or decreased mostly because more or less cement has been produced. The activity effect was responsible for an increase of 41.5 Mtons of CO₂

²⁶In the graphic we display variations from 1990 (fixed date) to year i . To compute variations between years i and j , we only have to take the differences, as the decomposition is linear and $\Delta_{i,j} = C_i - C_j = C_i - C_{1990} - (C_j - C_{1990}) = \Delta_{i,1990} - \Delta_{j,1990}$

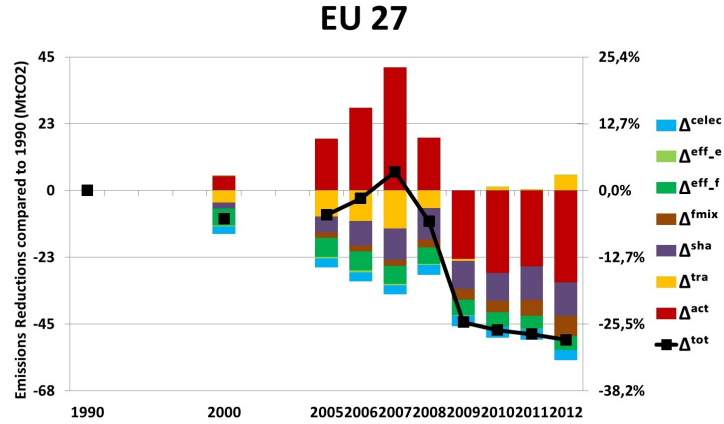


Figure 9: LMDI decomposition analysis of cement emissions compared to 1990. EU 27

in 2007 compared to 1990 (+22.7%) and for a decrease of 64.5 Mtons of CO₂ two years later (corresponding to a 34.2% decrease).

At the European level, the clinker trade effect partially compensates the activity effect most of the time: it is negative when the activity effect is positive and vice-versa. Put differently, a production increase is accompanied by an increase in clinker net imports and a production decrease by a decrease in clinker net imports, which can be explained by production capacity constraints (Cook, 2011). Keeping 1990 as the reference level, the clinker trade effect was at its highest in 2007 when clinker net imports reached 14.1 Mtons. At this time, 12.8 Mtons of CO₂ (7% of 1990 emissions) were avoided in Europe because of clinker outsourcing. With the economic downturn and the decrease in overall production, clinker net imports dropped and Europe became a clinker exporter in 2009. Between 2007 and 2010, while the activity effect led to a decrease of 69.2 Mtons of CO₂, the change in the balance of the clinker trade was responsible for an increase of 13.9 Mtons of CO₂ in Europe.

The two most important levers of technological emissions reduction are clinker substitution and alternative fuel use. The clinker share effect led to a reduction of 5.4 Mtons of CO₂ in 2005 compared to 1990 (-3.0%) and an extra 5.9 Mtons in 2012 compared to 2005 (-3.4%). Alternative fuel use led to a reduction of 1.9 Mtons of CO₂ in 2005 compared to 1990 (-1.0%) and an extra reduction of 5.1 Mtons between 2005 and 2012 (-2.9%).

Thermal energy efficiency was the most important driver of emissions reduction in the 1990s: between 1990 and 2000, it induced a decrease of 5.7 Mtons of CO₂ (-3.2%). Since then, thermal energy efficiency in Europe has stagnated, generating no extra emissions reduction. The electrical energy efficiency effect has by far the least influence. It led to 0.5 Mtons of CO₂ of emissions reduction between 1990 and 2005. Then a deterioration in electrical energy efficiency led to an increase of 0.7 Mtons of CO₂ between 2005 and 2012. There are two

possible explanations for the stagnation of thermal energy efficiency and the deterioration of electrical energy efficiency in the 2000s. First, kilns were operating below capacity and thus below their optimal efficiency level. Second, the two other main abatement options (clinker reduction and alternative fuel use) may reduce energy efficiency (see part 2.6).

Finally, the electricity carbon emissions factor effect has had a progressive impact in reducing cement emissions, globally small but not negligible. This channel of emissions reduction, which has the particular characteristic of depending on other stakeholders than the cement industry itself, was responsible for a decrease of 2.5 Mtons of CO₂ between 1990 and 2000 and 0.9 Mtons of CO₂ between 2000 and 2012 (-1.4% then -0.5%).

These observations can be summarised as follows. Clinker substitution, alternative fuel use, and to a lesser extent decarbonisation of electricity, have brought a continuous decrease in carbon emissions over the past twenty years (respectively 11.3, 7.0 and 3.3 Mtons of CO₂ between 1990 and 2012, i.e. 6.2%, 3.8% and 1.8% reduction). Together they are responsible for a 11.9% decrease in carbon emissions. Energy efficiency induced a decrease in emissions in the 1990s (5.7 Mtons of CO₂ or -3.2% between 1990 and 2000) then a small increase, probably because of clinker share reduction and alternative fuel use. Overall it was responsible for 4.7 Mtons of emissions reductions between 1990 and 2012 (-2.6%). Apart from this long-time slow trend of emissions reduction, most of the emissions fluctuations are explained by the activity effect, which is partially compensated for by the clinker trade effect.

4.2. Main European producers

Figures 10 to 15 show information, using the same graphical format, for the biggest European cement producers: Germany, France, Spain, the UK, Italy and Poland. We do not give such a detailed analysis for each country as for the EU 27 but only highlight the most salient facts.

- *Germany.* Germany shows that it is feasible to decrease significantly emissions intensity. Clinker substitution and alternative fuel use have allowed significant emissions reductions (-23% between 1990 and 2012). Moreover, Germany was exporting clinker at the peak of economic activity in 2007 while EU 27 as a whole was importing it. It is the only big Western European country which did not have a sharp decrease in cement production. Cement production was only 2% lower in 2012 than in 1990, while carbon emissions were 27% lower.
- *France.* France reduced emissions while making virtually no technological improvement between 2000 and 2012. In the 1990s the cement French market got consolidated (only four companies were in activity in 2005, contrary to Germany, Italy and Spain where the market is more fragmented), which involved many plant closures. This could explain why the activity effect and the clinker trade effect did not move in opposite directions between 1990 and 2000 (the decrease in cement production, around 20%, by

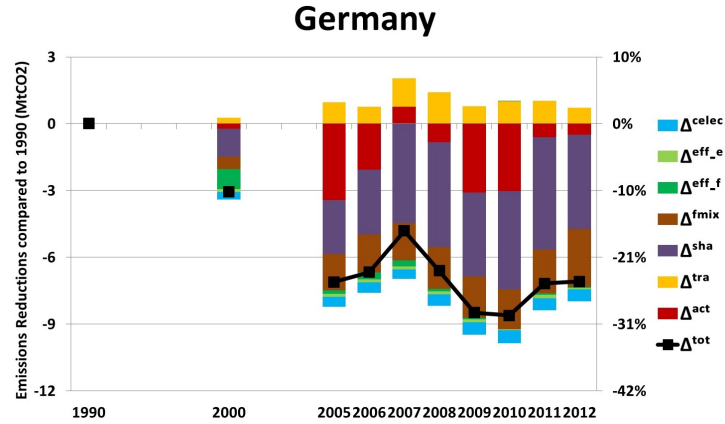


Figure 10: LMDI decomposition analysis of cement emissions compared to 1990. Germany

far more important than its European counterparts, was accompanied by a rise in clinker net imports). The clinker share effect, after being responsible for an increase in emissions until 2006, brought emissions reductions afterwards, returning approximately to its 1990 level, whereas in most European countries (except Italy) it has been a continuous source of significant emissions reductions. Energy efficiency, which was the best among the big Western European countries in 1990, has deteriorated continuously and led to an increase in emissions. The biggest source of emissions reduction, alternative fuel use, was only applied in the 1990s: hardly any improvement was achieved afterwards.

- *Spain*. Spanish cement emissions are overwhelmingly affected by the activity effect and the clinker trade effect. At the highest point of the housing bubble in 2007, the activity effect would have doubled emissions (+105%) compared to 1990, but was partially compensated for by the clinker trade effect (-42%). The bursting of the housing bubble led to a massive reduction in cement production and therefore of emissions through the activity effect, which was partially offset by a massive reduction in clinker net imports, and an increase in the clinker-to-cement ratio. Still, some emissions reduction was achieved by alternative fuel use (especially since 2010), thermal energy efficiency, and electricity decarbonisation, bringing altogether 7.8% of emissions reductions in 2012 compared to 1990.
- *UK*. In 1990 the UK cement industry was the most CO₂-intensive in Western Europe. However, twenty years later it was one of the best performers. The reduction of the exceptionally high clinker-to-cement ratio (94% in 1990) down to 70% in 2012 led to massive emissions reductions (a 18% decrease compared to 1990). Other levers of emissions reduction such as energy efficiency and alternative fuel use were applied to a significant extent.

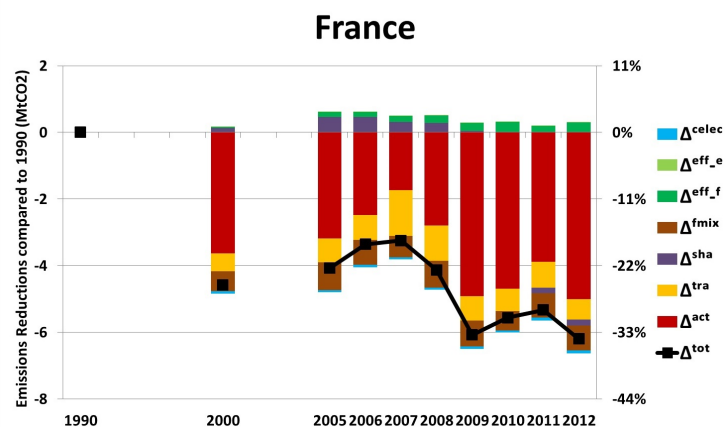


Figure 11: LMDI decomposition analysis of cement emissions compared to 1990. France

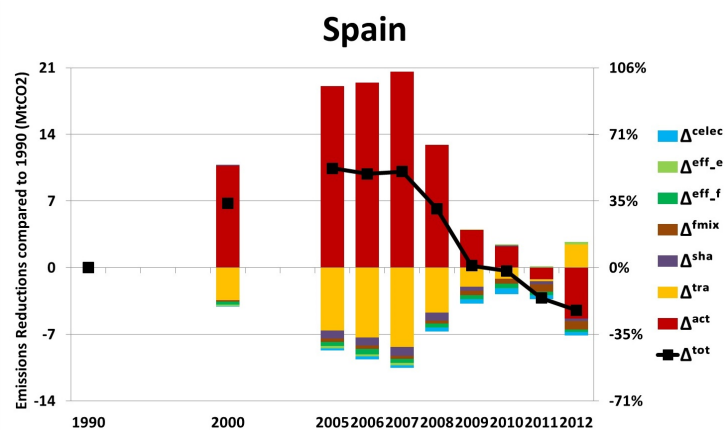


Figure 12: LMDI decomposition analysis of cement emissions compared to 1990. Spain

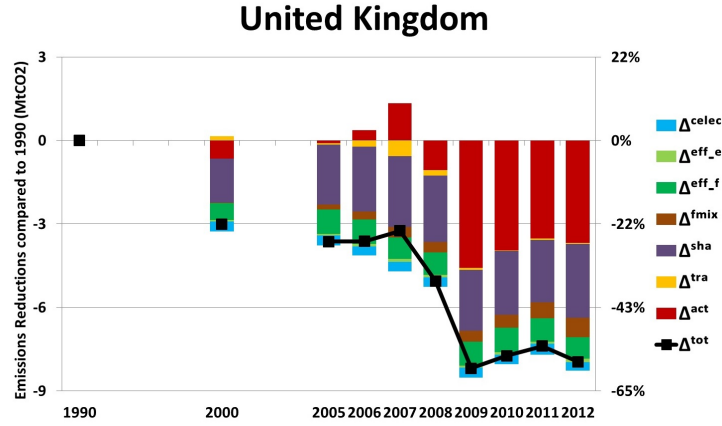


Figure 13: LMDI decomposition analysis of cement emissions compared to 1990. the UK

On top of all these factors, the economic downturn led to a considerable decrease in emissions in 2008 and 2009 with a small rebound afterwards (whereas the activity effect was responsible for a small increase in emissions in 2005-2007). Overall, the UK is the major European country with the biggest fall in emissions in 2012 compared to 1990 (-58%, compared to -25% in Germany, -34% in France, -40% in Italy, -23% in Spain and -6% in Poland).

- *Italy.* Like France, Italy had good environmental indicators in 1990 such as the lowest clinker-to-cement ratio and a relatively low carbon intensity of the fuel mix. While being a major source of emissions reductions in other countries, the clinker share effect led to an increase in emissions in Italy, because of the increase in the clinker-to-cement ratio in the 1990s and its stabilization in the 2000s. Moreover, since 2000, barely any progress has been made in energy efficiency and alternative fuel use. The activity effect has had a qualitatively similar impact as in the UK (as Italy produces approximately twice as much cement, the effect is twice as small in percentage terms). Overall, the 40% emissions reduction compared since 1990 is almost entirely explained by the activity effect.
- *Poland.* Unlike the other European countries, Poland has had a sustained increase in production (only slightly hit by the recession). In 2012 the activity effect was responsible for a 27% increase in emissions compared to 1990. Most of this increase was compensated for by other sources of emissions reductions, explaining why emissions decreased by 6% in 2012 compared to 1990. The biggest contribution to emissions reduction was from energy efficiency, mostly in the 1990s, but clinker substitution and alternative fuel have had a significant impact.

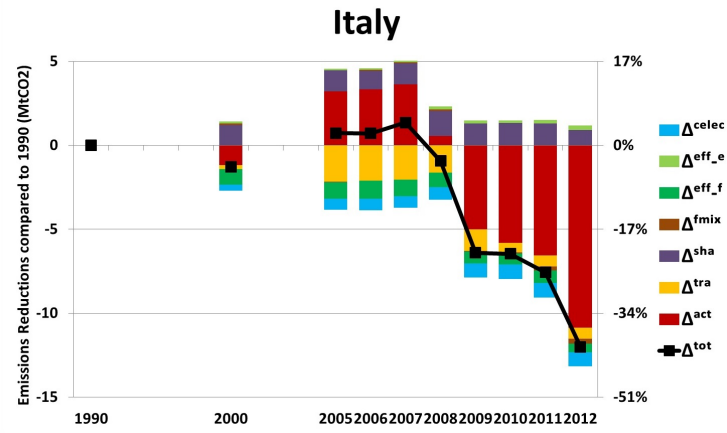


Figure 14: LMDI decomposition analysis of cement emissions compared to 1990. Italy

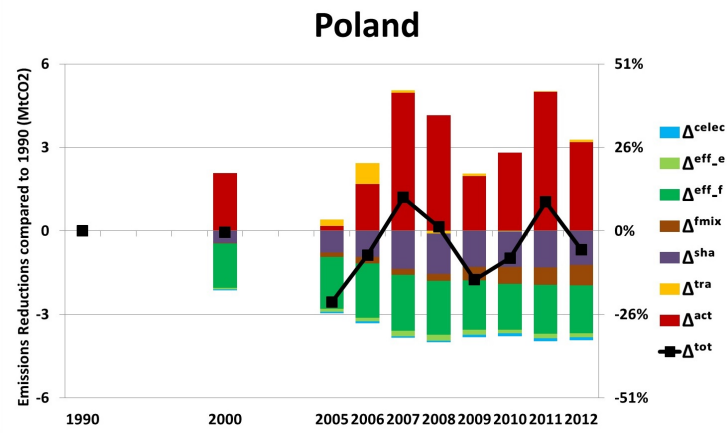


Figure 15: LMDI decomposition analysis of cement emissions compared to 1990. Poland

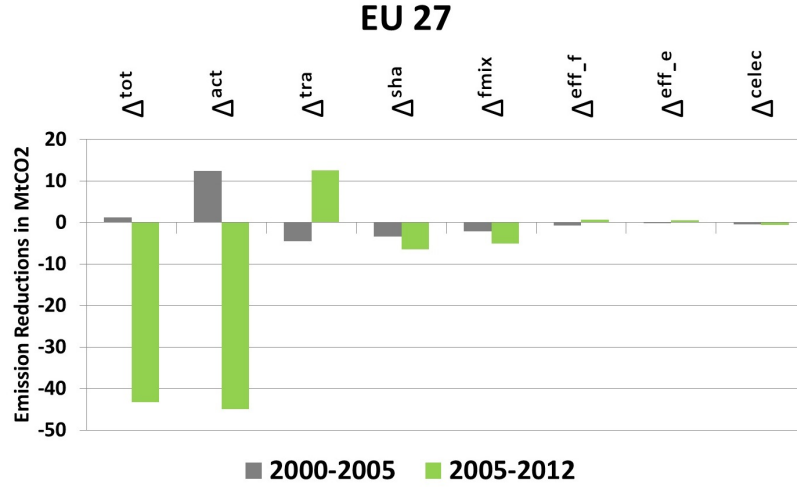


Figure 16: LMDI decomposition analysis of cement emission variations in the EU 27, before and after the beginning of the EU ETS (2000-2005 and 2005-2012)

5. Impact of the EU ETS on the cement industry

5.1. Overview

Figure 16 shows the results of the LMDI decomposition before (2000 and 2005) and after (2005-2012) the launch of the EU ETS.

Between 2000 and 2005, cement industry emissions increased by 0.7%, whereas between 2005 and 2012 they dropped by 24.9%. This gives the impression that the EU ETS was extremely efficient at reducing emissions. However, the LMDI analysis shows that the activity effect itself accounts for 25.9% of emissions reduction between 2005 and 2012, compensated for by a 7.2% increase in the clinker trade effect. This decrease in clinker net imports is essentially due to weak domestic demand leading to production overcapacity.

Among the technological abatement options, between 2005 and 2012, the clinker share effect, the fuel mix effect and the decarbonisation of electricity led to emission reductions of 3.8%, 2.9%, and 0.4% respectively, compensated for by a 0.4% increase due to the energy efficiency effect. Before the beginning of the EU ETS, between 2000 and 2005, the clinker share effect, the fuel mix effect, the carbon emissions factor effect and the energy efficiency effect led to emissions reductions of 2.0%, 1.2%, 0.3%, and 0.4% respectively.

It would thus seem that the introduction of the EU ETS may have, to a small extent, accelerated the use of clinker substitution, alternative fuel use and decarbonisation of electricity²⁷, while these mitigation options may have led to

²⁷Though most of the decarbonisation of electricity may be due to renewable subsidies rather than the EU ETS itself (Weigt et al., 2013).

a decrease in energy efficiency.

Figure 16 does not show *abatement* but simply *changes* in emissions over time. Abatement is the difference between *actual* emissions and *counterfactual* emissions, which would have occurred if the EU ETS had not existed. Quantitative estimation of the abatement due to the EU ETS therefore necessitates the construction of a counterfactual scenario. The methodology and results are given in the next section.

5.2. Abatement

The method has three stages. First, we produce two counterfactual scenarios making assumptions about the different parameters of the emissions decomposition detailed in section 3.1. Second, we compute the difference $C_t^{real} - C_t^{counterfact}$ for each year, then decompose it through an LMDI decomposition analysis. Third, we add the different yearly effects and analyse the different levers of abatement. In this section and the next one, we consider the geographically changing EU ETS perimeter²⁸ instead of the EU 27, as we study the impact of the EU ETS on the cement industry.

For the counterfactual scenario, we assume that both the quantity of cement produced ($Q_{cement,t}^{counterfact} = Q_{cement,t}$), and the home production ratio ($H_t^{counterfact} = H_t$) remain unchanged. The EU ETS may have led to greater levels of production after the economic recession because of the allowance allocation method (which discourages plant closure); or conversely to lower levels of production because of cement substitution (lever (i)), loss of competitiveness and leakage incentives (which have not been empirically proven so far, see Branger et al. (2013b)); but these effects are likely to be small.

For the other variables, R_t , the clinker-to-cement ratio, $CEF_{F,t}$ the carbon intensity of the fuel mix, $I_{En,t}$, the thermal energy intensity of production, $I_{El,t}$, the electrical energy intensity of production and $CEF_{elec,t}$, the electricity emission factor; we consider two counterfactual scenarios. In the “Freeze” scenario, the variables keep their 2005 values from 2005 to 2012. In the “Trend” scenario, the variables decrease (or increase) at the same rate as the average yearly variation between 2000 and 2005²⁹.

As an example, let us consider a given country for which the clinker-to-cement ratio is 80% in 2000 and 77% in 2005 (which corresponds to an average decrease of 0.8% per year). In the “Freeze” scenario, the clinker-to-cement ratio

²⁸The EU 27 minus Romania and Bulgaria until 2007, plus Norway, Lichtenstein and Iceland after 2008. However, data for Cyprus and Bulgaria are not available until 2008, and UK data are inaccurate for phase I because of the opt-out condition. The geographical perimeter considered at the European level is guided by the available EUTL data coverage (so only a part of UK production is considered in phase I). The production of clinker and cement as well as net imports have been modified to take into account the changing geographical perimeter.

²⁹Ideally we would have used the 2004 values if they had been available in the GNR database as in this method technological abatement is necessarily zero in 2005. However some time was probably needed for cement companies to adapt and take the EU ETS into account in their operational decisions.

will stay at 77% from 2005 to 2012. In the “Trend” scenario, the clinker-to-cement ratio will start at 77% in 2005 and decrease by 0.8% per year, to finish at 73.5 % in 2012. In this case, the estimated abatement will be higher in the “Freeze” scenario, since the counterfactual scenario is more pessimistic (higher emissions).

Estimating what would have happened in the absence of an event (here the introduction of the EU ETS) is in itself very challenging. Suggesting that parameter values would have ranged between the “Freeze” and “Trend” scenarios is a rule of thumb that is admittedly simplistic, but has the virtue of avoiding the setting of arbitrary values for the parameters. Table 3 displays results when this method is applied for predicting 2005 values in the EU 28. Except for the clinker-to-cement ratio and the carbon intensity of the fuel mix, slightly out of the interval, the order of magnitudes are fairly correct³⁰.

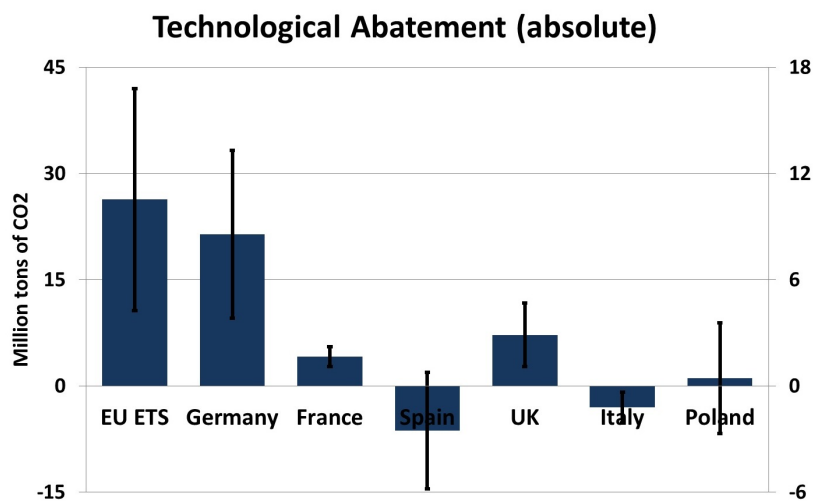
Table 3: Verification. Do the “Freeze” and “Trend” scenarios provide a good interval for changes in variables over time? Application on year 2005 for the EU 28 using 1990 and 2000 values. In this case, 2005 “Freeze” values are equal to 2000 values, and the trend rate is the one between 1990 and 2000.

Variable	Unit	1990	2005 “Freeze”	2005 Real	2005 “Trend”	Observation
R_t	%	78.4%	77.5%	75.9%	77.1%	overestimation
$I_{En,t}$	GJ per ton of clinker	4,07	3,73	3,69	3,57	Interval OK
$I_{El,t}$	kWh per ton of cement	114	110	109	108	Interval OK.
$CEF_{F,t}$	kgCO ₂ /GJ	90.9	91.3	88.3	91.5	overestimation
$CEF_{elec,t}$	kgCO ₂ /MWh	474	381	363	342	Interval OK

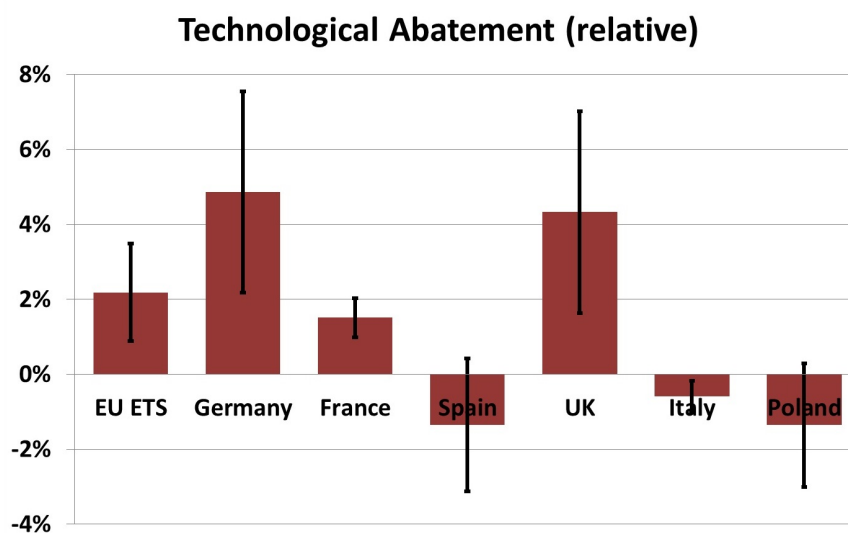
Figure 17 shows the results of the abatement estimates. Values shown correspond to the average of the two scenarios, and with the original values of scenarios as the error interval. We find that between 2005 and 2012, the European cement industry abated 26 Mtons (± 16 Mtons) of CO₂ emissions, which corresponds to a decrease of 2.2% ($\pm 1.3\%$) in emissions. However, this abatement could be due to an external cause - energy prices - rather than to the EU ETS. Indeed the prices of steam coal and petcoke (the two main energy sources used to produce clinker) roughly doubled from 2003-4 to 2010-11 as the graphs on p.31 of Cembureau (2012) show³¹. Increasing “conventional energy” prices reinforce the profitability of using substitutes rather than clinker, alternative fuels, and increasing energy efficiency.

³⁰Our counterfactual is likely to be more precise for two reasons. First, the trend is based on a shorter term (5 years instead of 10). Second, 1990 was the first year for which data is collected, which was done in 2005. Then the level of assurance of 1990 details is not to the standard of later years.

³¹Steam coal and petcoke prices have fallen since 2011, due, among other reasons, to the shale gas boom in the US. If the downward trend persists, a degradation of the cement performance indicators would support this explanation.



(a) Absolute abatement (left axis for the EU ETS perimeter, right axis for the others) in millions of tons.



(b) Relative abatement as a percentage of total emissions

Figure 17: “Technological” abatement between 2005 and 2012. The bars correspond to the “Freeze” scenario estimates (the top bar except for France) and the “Trend” scenario estimates (the bottom bar except for France).

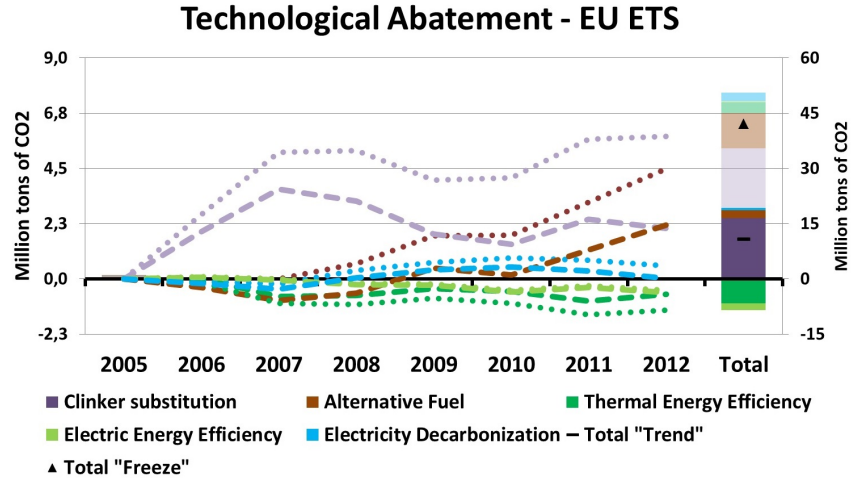


Figure 18: Technological abatement in the EU ETS perimeter. The curves on the left side show the abatement due to the different effects under the “Freeze” scenario (dotted line) and the “Trend” scenario (dashed line). The histogram on the right gives the sum of abatements over the years, in full color for the “Trend” scenario, and in full color *plus* faded color for the “Freeze” scenario.

Germany is the European country that has abated the most in absolute terms (9 Mtons \pm 5 Mtons) and in percentage terms with the UK³² ($-4.9\% \pm 2.7\%$ and $-4.3\% \pm 2.7\%$). The abatement in France is small but positive ($-1.5\% \pm 0.5\%$) while the abatement in Italy is small but negative ($+0.6\% \pm 0.4\%$). The uncertainty in the evaluation of abatement in Spain and Poland is high (but both average values are negative).

The results described above come from a simple difference between actual and counterfactual emissions. An LMDI decomposition analysis allows us to investigate what levers have been used to provide actual abatement. The results are shown in Figure 18. Almost all of the technological abatement in the EU ETS perimeter comes from clinker share reduction (between 16 and 32 Mtons of CO₂) followed by alternative fuels (between 2 and 12 Mtons of CO₂), while the decrease in energy efficiency led to negative abatement (between 4 and 7 Mtons of CO₂).

The detailed results, country by country, are given in the Appendix and a summary of the results is given in Table 4. Clinker reduction is the main lever of technological abatement and led to actual abatement in Germany, France, the UK, and Poland but negative abatement in Spain and Italy. In all countries except France, abatement due to clinker substitution decreased (being negative in some countries) after the economic downturn. This could be explained

³²For the UK at the national level, we use corrected GNR data for emissions for phase I as in the previous section because of the inaccuracy of EUTL data.

by overcapacity and excess clinker production. Alternative fuel led to positive abatement in Spain, the UK and Poland and negative abatement in other countries (in France and Germany it could be because decarbonisation of the fuel mix had already started before the beginning of the EU ETS, so the “Trend” scenario gives lower emissions and actual abatement is harder to achieve). The thermal energy efficiency effect brought positive abatement in Germany, was neutral in the UK and brought negative abatement in France, Italy, and Poland. The electric energy efficiency effect brought positive abatement in the UK and Poland, was neutral in France and brought negative abatement in Germany, Italy and Spain. Electricity decarbonisation led to positive abatement in France, Spain, the UK and Italy and was insignificant in Germany and Poland.

Table 4: Impact of different technological options on technological abatement

	EU ETS	Germany	France	Spain	UK	Italy	Poland
Clinker reduction	+	+	+	−	+	−	+
Alternative fuel	+	−	−	+	+	=	+
Thermal Energy Efficiency	−	+	−	=	=	−	−
Electric Energy Efficiency	−	−	=	−	+	−	+
Elec Decarbonisation	+	=	+	+	+	+	=

Note: a + in clinker reduction means that clinker reduction indeed provided positive technological abatement. = stands for indeterminate (when the error interval overlaps zero in the decomposition)

5.3. Overallocation profits

Numerous studies have demonstrated that electricity companies have reaped windfall profits by passing through the allowance price to their consumers while they had received the allowances for free (Sijm et al., 2006). Indeed, even allocated free of charge, allowances can be sold and therefore have an opportunity cost.

The ability to pass through the allowance price to consumers has not been well-established for cement companies. Economic theory suggests that for linear demand curves, pass-through rates are higher in competitive markets than in monopolies (because prices are more directly linked to marginal production costs), and for markets with elastic supplies and inelastic demands (Sijm et al., 2008; Wooders et al., 2009). The cement industry is an oligopoly with moderately elastic supply and inelastic demand (Selim and Salem, 2010), which would suggest moderately-high pass-through rates (75-80%) (Oxera Consulting, 2004). To our knowledge, the only two empirical studies of pass-through rates in the European cement sector are to our knowledge an old study from Walker (2006), which unveils positive but moderate pass-through rates for 2005 (25-35%, depending on the country), and Alexeeva-Talebi (2010) for the German cement, lime and plaster sector finding a higher pass-through (73%).

In this article, we focus on another source of “windfall” profits obtained from the EU ETS: overallocation profits. The principle of overallocation profits

is straightforward. When the number of EUAs³³, given free of charge to cement companies, is higher than emissions necessary to manufacture the amount of cement really produced; a surplus of EUAs is automatically generated. These allowances can then be sold and will generate profits.

If we eliminate emissions due to electricity consumption from equation (7), which are not accounted for by cement companies in the EU ETS, we have the equation:

$$C_{EUTL,t} = Q_{cement,t} \times R_t \times H_t \times (CEF_{pro} + I_{En,t} \times CEF_{F,t}) \quad (13)$$

where $C_{EUTL,t}$ are direct emissions, $Q_{cement,t}$ is cement production, H_t the clinker home production ratio, CEF_{pro} the process emissions, $I_{En,t}$ the energy intensity and $CEF_{F,t}$ the carbon intensity of the fuel mix.

With the given state of technology in the EU 28 in 2005, and no clinker trade ($H = 1$), an allocation cap A_t allows the production of a certain quantity of cement $Q_{cement}^{A_t}$ without buying or selling allowances:

$$\begin{aligned} Q_{cement}^{A_t} &= \frac{A_t}{R_{EU28_{2005}}(CEF_{pro} + I_{En,EU28_{2005}} CEF_{F,EU28_{2005}})} \\ &= \frac{A_t}{C_e C I_{EU28_{2005}}} \end{aligned} \quad (14)$$

with the cement carbon intensity of the EU 28 in 2005 ($C_e C I_{EU28_{2005}}$) being 656 kg of CO₂ per ton of cement³⁴. In the rest of the article we will call $Q_{cement}^{A_t}$ the “production equivalent associated with the cap A_t ”.

We compute the difference between *actual* emissions C_t (associated with values $Q_{cement,t}$, R_t , H_t , $I_{En,t}$ and $CEF_{F,t}$) and the *reference* situation corresponding to the cap A_t (associated with values $Q_{cement}^{A_t}$, $R_{EU28_{2005}}$, $H = 1$, $I_{En,EU28_{2005}}$ and $CEF_{F,EU28_{2005}}$); and decompose it³⁵ using the same LMDI decomposition method as in section 4. We then keep the activity effect, the clinker trade effect, and group the other effects under the name “technology” effect.

The technology effect gives the proportion of the EUAs surplus due to technological performance, while the activity and clinker trade effects give the proportions of the EUAs surplus due to underactivity and clinker outsourcing. Overallocation is then defined as the sum of the activity and clinker trade effects. The computed overallocation can be seen as the difference between actual

³³for the European Union Allowance, the “standard” allowance. Allowances from offset credits are CER (Certified Emission Reductions) for Clean Development Mechanisms and ERU (Emissions Reduction Units) from Joint Implementation.

³⁴Calculated with the EU 28 values in 2005 of R , CEF_{pro} , I_{En} and CEF_F which are respectively 75.9%, 0.538 tCO₂/ton of clinker, 3.69 GJ/ton of clinker and 0.0883tCO₂/MJ.

³⁵We use the EU ETS value of CEF_{PRO} in this section, as the heart of the question is the EUAs surplus and not “real” emissions.

allocation and output-based allocation, based on current clinker production with a certain level of technology (European average in 2005).

We choose to base the reference situation for technological performance on the 2005 European average values so that the reference situation brings *zero extra costs on average at the European level*. The estimation of overallocation is then rather conservative, another option could have been to take the technological performance of the best-performing installations, as in the phase III benchmarking (Ecofys et al., 2009).

Figure 19 shows the decomposition of the EU ETS allowances surplus over time. The EUAs surplus is the sum of the activity effect, the trade effect and the technology effect; which are positive respectively when production is lower than the production equivalent associated with the cap ($Q_{cement}^{A_t}$), when net imports are positive, and when cement carbon intensity is lower than the 2005 EU 28 level. Overallocation, the sum of the activity and trade effects, can be negative (in this case there is underallocation) when cement production is high and/or the region is exporting clinker. It can also be higher than the EUAs surplus if the technology effect is negative (high cement carbon intensity). The activity and trade effect can cancel each other out, leading to no overallocation, for example when a region is producing a high quantity of cement but importing clinker.

We also add to the EUAs surplus the offset credits used by the cement industry to show the “real” allowances surplus. Indeed, European authorities allowed companies to use offset credits (CERs or ERUs) to meet emissions caps during phase II. The offset limit as a share of allocations was not harmonized at the European level but differed among member states: 22% for Germany for example but only 8% in the UK (Vasa, 2012). Companies could directly finance projects and receive offset credits or purchase offset credits in the secondary market (including pure swapping of EUAs to exploit the spread and maximize trading profits).

The first year that the EU ETS came into force, the overall cap was slightly too generous with an overallocation of 12 million EUAs (roughly 8% of the cap). The increase in production in the following two years because of economic growth, and a housing bubble in certain countries, while the cap was unchanged, led to a reduction in the overallocation. Given European production levels at that time, there would have been underallocation had net imports not been so massive. In 2005, 2006 and 2007, roughly 30 million EUAs were saved thanks to the outsourcing of 9, 11 and 14 Mt of clinker respectively.

The economic downturn after 2008 led to a sharp decrease in production and therefore a massive surplus of EUAs. We estimate that the low level of activity brought 47, 52, 50 and 56 million of overallocated EUAs in 2009 to 2012 respectively (between 25% and 32% of the annual cap). After 2009, Europe became a net exporter of clinker (up to 6 Mt of clinker in 2012), so the clinker trade effect brought negative overallocation (e.g. underallocation) of 10 million EUAs (1.5% of the cap). Of the EUAs surplus for phases I and II, 45 million

Overallocation - EU ETS

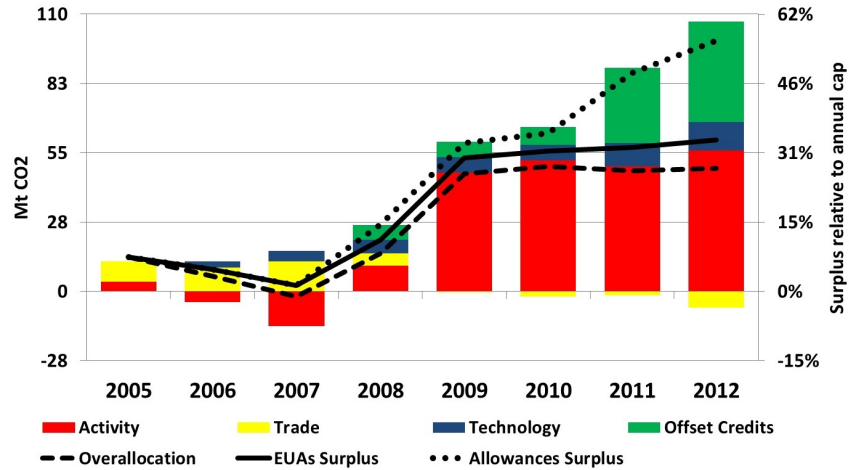


Figure 19: Overallocation over time in the EU ETS perimeter.

EUAs (3% of the cap) can be attributed to the technology effect³⁶. For phase II, 84% of the surplus of 248 million EUAs was due to overallocation.

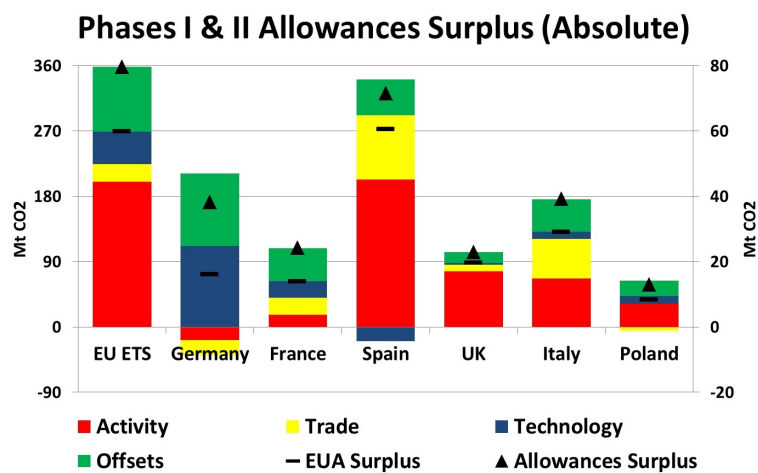
While having an excess of allowances, companies made intensive use of project-based credits. Sandbag data at the installation level reveals that virtually all cement installations used offset credits, and that the overwhelming majority of them surrendered credits up to a fixed share of allocation, which can be inferred at the maximum amount authorized for cement installations in each country³⁷: 22% in Germany, 13.5% in France, 7.9% in Spain, 8.0% in the UK, 7.5% in Italy and 10% in Poland. In total, 89 million offset credits were used, representing 10% of the cap. The total surplus for phase II was then 337 million allowances, representing almost the equivalent of two years of allocation.

Figure 20 displays the decomposition³⁸ of the phase I and II allowances

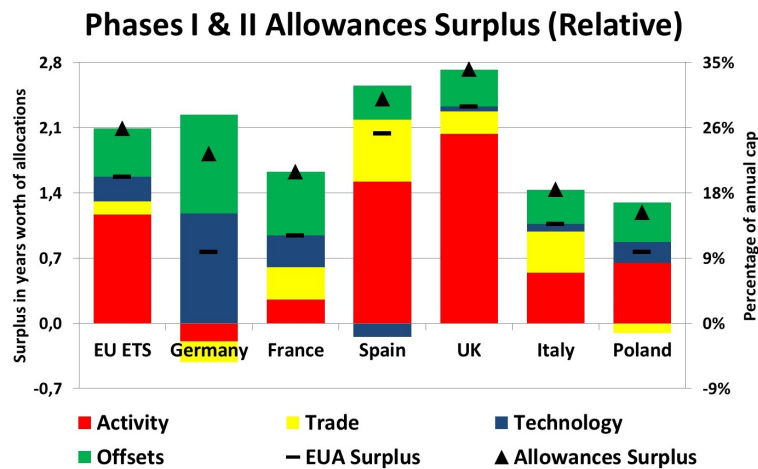
³⁶This corresponds to a “Freeze” scenario for which cement production would have been equal to the production equivalent associated with the cap, which was higher than actual production, which is why this figure is higher than the “Freeze” scenario of the previous section (42 million).

³⁷For Spain (20.6%) and Italy (15%), there is a discrepancy between the share of allocation authorized at the *national* level in Vasa (2012) and the one we found at the cement installation level. An explanation could be that in these two countries the proportion of offset was probably differentiated among sectors at the installation level.

³⁸For computing overallocation per country we chose to consider a European average benchmark rather than a national benchmark to put each country on an equal footing. However as the guiding principle of allocations in phase I and II was grandfathering, we also performed computations with national carbon intensities of cement (respectively 618, 637, 672, 710, 644 and 660 kgCO₂ per ton of cement in Germany, France, Spain, the UK, Italy and Poland). For a given cap, a lower carbon intensity of cement will correspond to a higher equivalent quantity



(a) Decomposition of the allowances surplus (left axis for the EU ETS perimeter, right axis for main European countries)



(b) Decomposition of the allowances surplus, in years worth of allocations or relative to average annual cap

Figure 20: Decomposition of the allowances surplus

surplus at the EU ETS level and for the main European producers³⁹. A complete year by year decomposition (as in Figure 19) is available in the Appendix for each country.

The cumulated overallocation at the EU ETS level for phases I and II is estimated at 224 million EUAs (89% due to the activity effect and 11% due to the trade effect). The country with by far the highest overallocation is Spain (65 million EUAs) followed by Italy (27 million EUAs), because of massive clinker imports in phase I and large falls in production in phase II.

In these two countries, while the overallocation in phase II is overwhelmingly dominated by the activity effect, the impact of the trade effect on cumulated overallocation for phases I and II is significant (33% for Spain and 42% for Italy). Indeed there was a negative activity effect in phase I (higher production than the production equivalent associated with the cap) which cancels out some of the positive activity effect (underproduction) in phase II. Conversely, there was no significant negative trade effect in phase II to cancel out the positive trade effect in phase I. Italy continued to be a clinker importer in phase II while Spain's net exports after 2009 were much smaller in magnitude than its net imports before the crisis.

Overallocation was also positive in France (9 million EUAs, more than half of it due to trade) and Poland (6 million EUAs, with a negative trade effect), while there was actually underallocation in Germany (minus 9 million EUAs, due to high production after 2008 and clinker exports). In relative terms, overallocation was also the highest in Spain and the UK (2.2 years worth of allocations) followed by Italy (0.9).

The technological performance varies significantly across countries and so does the share of the technology effect in the EUAs surplus (which is 45 million EUAs at the EU ETS level). Germany ranks first with 25 million EUAs earned thanks to low cement carbon intensity, followed by France (5 million EUAs). The technology effect is very small in the UK, Italy and Poland (0, 2, and 2 million EUAs respectively) and even negative in Spain (minus 4 million EUAs). In relative terms, Germany is also first (1.2 years worth of allocations) followed by France (0.3).

As mentioned above, because the thresholds vary from country to country, the number of surrendered offset credits varied significantly among member states. During phase II, they represented 21.1%, 13.3%, 7.4%, 6.7%, 7.2% and 8.4% of annual EUAs cap in Germany, France, Spain, the UK, Italy and Poland respectively. These differences raise concerns about equity between member states, that add to concerns about the equity of national allocation plans. For-

of cement, and thus to a higher surplus and higher overallocation profits due to activity. The only noticeable difference is for Germany: because of its high technological performance, the alternative computation led to a smaller technology effect and a greater (and positive) activity effect, and thus no underallocation. For the other countries the differences are not significant.

³⁹In this section, for UK at the national level we use EU ETS data rather than GNR corrected data though the coverage is incomplete, because the key question is the EUAs surplus.

unately, member states with the most stringent allocation plans were generally the most generous regarding the use of offset credits (see Table 5). The use of offset credits has made Germany’s allowances surplus more than double the EUAs surplus (38 million allowances compared to 16 million EUAs, representing an increase of 140%). The impact of offset credits on the surplus was also relatively significant in France (+72%) and Poland (+55%) but less so in Italy (+34%), Spain (+18%), and the UK (+17%).

Table 5: Decomposition of phase II allowances surplus

	EU ETS	Germany	France	Spain	UK	Italy	Poland
EUAs Surplus (millions)	248	7	14	58	19	34	5
EUAs Surplus (% cap)	28%	7%	18%	39%	39%	25%	9%
Technology Effect (MEUAs)	38	17	3	-3	1	1	2
Activity Effect (MEUAs)	215	-7	8	62	17	28	3
Trade Effect (MEUAs)	-5	-3	3	-1	1	6	0
Overallocation (% Surplus)	84%	-138%	77%	105%	93%	97%	54%
Offsets (millions)	89	22	10	11	3	10	5
Offsets (% cap)	10.4%	21.1%	13.7%	7.4%	8.0%	7.3%	8.5%

After having decomposed the allowances surplus and computed overallocation, let us turn to overallocation profits and offset savings. To estimate overallocation profits, we multiply yearly overallocation by the yearly average allowance spot price⁴⁰. If negative, overallocation profits correspond to underallocation profit losses. If overallocation can be estimated with a high degree of accuracy, overallocation profits are more difficult to estimate because carbon prices vary within a year and, more importantly, allowances can be banked except from phase I to phase II. It is well-known that companies have kept a significant share of allowances as a hedge against a future scarcity).

To estimate a lower limit of savings brought by offset credits, we multiply yearly surrendered offset credits by yearly EUA-CER spread values given by Stephan et al. (2014) (4.05€, 1.54€, 2.06€, 3.34€ and 4.87€ from 2008 to 2012 respectively). Actual savings are higher for two reasons. First, if companies originate the projects, actual costs of project-based credits are much lower and savings are thus higher (for example a HFC gas project can bring offset credits less than a few Euros per ton of CO₂, bringing more than ten Euros of savings per allowance before 2012). Second, the use of offset credits increased the global cap and therefore decreased the EUA price (Stephan et al., 2014).

Results are shown in Figure 21. We estimate overallocation profits at the EU ETS level at 3.5 billion Euros. Overallocation profits would have been higher with higher EUA prices, but the latter dropped precisely because of a surplus of

⁴⁰Obtained by Tendances Carbone of CDC Climat (<http://www.cdcclimat.com/-publications-.html>), from 2005 to 2012 respectively: 18.04€, 17.3€, 0.7€, 22.2€, 13.1€, 14.3€, 13.0€ and 7.4€).

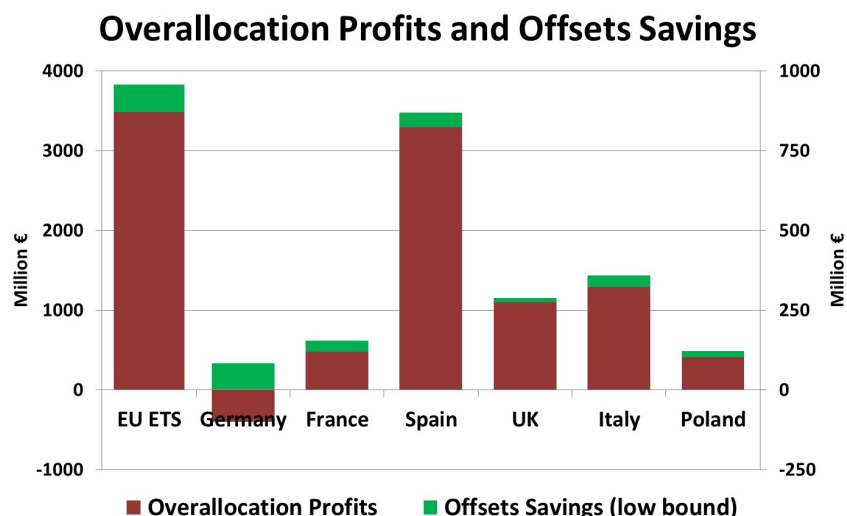


Figure 21: Overallocation profits and offset savings in the EU ETS perimeter (left axis) and main European countries (right axis)

allowances, which was the main cause of the overallocation profits. However the EUA price would have been higher had the offset credits not been authorized. The country with by far the highest overallocation profits is Spain (824 M€) followed by Italy (324 M€) and the UK (275 M€). Then come France (120 M€) and Poland (103 M€). Germany has 100 M€ of underallocation profit losses. A low bound of offset savings is assessed at 342 M€ at the EU ETS level, and Germany is the country that benefits the most with 83 M€.

Cumulated overallocation profits for the six countries reported is around 1.5 billion Euros, i.e. slightly less than half of overallocation profits at the EU ETS level, whereas they account for two thirds of allocations. We can surmise (based on EUTL data of EUAs surplus) that overallocation profits were particularly high because of the activity effect in Romania, Bulgaria, Greece, Cyprus, Hungary and Ireland where the accumulated EUAs surplus in phase II roughly corresponded to two years of allocations.

Discussing overallocation profits by company and not by country is also relevant as the European cement market is dominated by a few multinational companies (see Table 6). In the case of the EU ETS, we find that the five and fifteen biggest firms account for 56% and 86% of emissions in phase II respectively. Unfortunately, the GNR database only distinguishes countries and not companies, so the only information we can obtain is the EUAs surplus through the EUTL database and the offset credits used through the Sandbag database. A rough estimate (considering that among the total 3.5 G€ of overallocation profits, companies' overallocation profits are proportional to their EUAs surplus) leads to overallocation profits of 679M€, 436M€, 370M€, 364M€ and 328M€ for Lafarge, HeidelbergCement, Holcim, Cemex and Italcementi respectively.

Table 6: The major European cement producers were present in many different countries in 2012

	% Emissions	Countries						
	Phase II	EU ETS	Germany	France	Spain	UK	Italy	Poland
Lafarge	15%	11	X	X	X	X		X
Heidelberg	14%	11	X			X		X
Holcim	10%	10	X	X	X		X	
Italcementi	11%	6		X	X		X	
Cemex	7%	5	X		X	X		X
Buzzi	7%	5	X				X	X

Lafarge declared in its annual reports⁴¹, from 2008 to 2012, 605 M€ of gains due to excess rights over actual emissions. This figure is not directly comparable to our estimation of overallocation profits, because an unknown (but small) fraction is due to technological performance (not considered as overallocation profits in our estimation), and more importantly because allowances can be banked.

Furthermore, our definition of overallocation profits leaves out offset credits. However, surrendering offset credits allows more EUAs to be banked (almost 40% more at the European level for phase II), and therefore increases gains due to excess rights over actual emissions which are reported by companies.

Based on all these points, we can estimate that the biggest European producer has sold at least half of the EUAs surplus, and we can infer a similar situation for the whole cement industry. Indeed, companies faced cash constraints because of the economic recession and selling EUAs provided an easy access to liquidity. These EUAs transfers have added to the downward trend of the carbon price (IETA, 2012), in turn decreasing the value of overallocation profits.

6. Conclusion

We have analysed and quantified the key drivers of carbon emissions from 1990 to 2012 in the European cement industry using an LMDI decomposition analysis. Most of the emissions changes in the EU 27 can be attributed to the activity effect. The clinker trade effect has counterbalanced approximately one third of the high activity effect in 2005-2008, because of high clinker imports at

⁴¹Lafarge annual reports for the years year 2008 to 2012 (Lafarge, 2009, 2010, 2011, 2012) in pages F29 for 2009 to 2011 and F31 for 2012. The gains are 85 M€, 142M€, 158M€, 136M€ and 84 M€ from 2008 to 2012 respectively. The same sentence is also copied and pasted into each annual report in year X: "For year X+1, based on our estimate of allowances to be received and based on our current production forecasts, which may evolve in case of market trends different that from those expected of today, the allowances granted should exceed our needs on a consolidated basis."

that period when production capacities were fully employed. In addition, since the 1990s there has been a slow trend of emissions reductions mostly due to the clinker share effect, but also to the fuel mix effect and the electricity emissions factor effect. Next, we have estimated technological abatement induced by the EU ETS. Because of a small acceleration in clinker reduction and alternative fuel use after 2005, 26 Mtons of CO₂ (± 16 Mtons) of emissions have been abated from 2005 to 2012, corresponding to a 2.2% ($\pm 1.3\%$) decrease. However these effects could have been due to the rise of energy prices rather than the EU ETS. Finally, decomposing the allowance surplus allowed overallocation and thus overallocation profits to be assessed. The cement industry reaped 3.5 billion Euros of overallocation profits during phases I and II, mainly because of the slowdown in production, while allowance caps were unchanged.

European cement companies have been suffering from the economic downturn through reduced sales, low return on investment (BCG, 2013) and a decline in profits (Bolscher et al., 2013). However, their financial situation would have been far worse had the EU ETS not been implemented. During phase II, the scheme was tantamount to a subsidy of 3.5 Euros per tonne of cement produced in Europe⁴², which significantly increased the profitability of the sector⁴³. Presented as a threat to competitiveness, the EU ETS has paradoxically boosted European cement industry competitiveness, when defined as a company's ability to earn (Quirion, 2010).

Since 2013 and the beginning of phase III, the EU ETS conditions have been less favorable for the cement industry, because of an increased stringency of the allocation methodology. The allocation is now based on the average of the 10% best-performing installations, corresponding to 766 kgCO₂ per ton of clinker (European Commission, 2011), and declines at a rate of 1.74% per year. However, this benchmark is then multiplied for each installation by the historical activity level (HAL), which is generally based on pre-crisis levels⁴⁴. Overallocation occurred in 2013 (emissions were 20% lower than the cap) and will go on for the years to come unless production significantly increases.

Because of high levels of uncertainty concerning future production levels, the difference between HAL and actual production can be very large. The choice of HAL thus has deep financial repercussions on companies: too high a HAL automatically brings overallocation profits while one that is too low induces losses of profit. Output-based allocations, which consists in linking directly allocations to production, have the desirable benefit of by-passing the

⁴²3.5 billion Euros of overallocation profits divided by 1 billion tonnes of cement produced.

⁴³Based on financial data (including reported sales of allowances), Boyer and Ponssard (2013) find that the EBIDTA/sales ratio (Earnings Before Investment, Depreciation, Taxes and Amortization) of the Western European cement industry for phase II would have been 26.3% without sales of allowances, instead of 32.9%. Furthermore, the impact would have been more significant had cement companies sold all these financial assets instead of banking a significant share.

⁴⁴The HAL is, except for changes in capacity, the median value of the annual activity during the period 2005-2008 or 2009-2010 (whichever is the highest) (European Commission, 2011).

determination of HAL and the potential overallocation profits or underallocation profit losses that accompany it. Given the order of magnitude of financial values at stake that have been reported in this analysis, this advantage outweighs by far potential drawbacks⁴⁵. Such a dynamic allocation (Borkent et al., 2014) would lead to fewer economic distortions and more incentives to reduce carbon emissions than the current allocation methodology. An alternative option would be full auctioning with the inclusion of importers (Neuhoff et al., 2014).

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⁴⁵These drawbacks include fluctuating cap, administrative complexity, or providing little incentive to reduce the consumption of polluting goods (Quirion, 2009). However, these defaults can be mitigated with an appropriate design and additional policies. An extended discussion of optimal design for output-based allocations and complementary policies, as well as the comparison between other anti-leakage policies is beyond the scope of this paper. For more information we recommend Dröge (2009), Branger and Quirion (2014), ? and Neuhoff et al. (2014).

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7. Appendix

7.1. Formulas

$$\Delta^{act-F} = \frac{C_{F,T} - C_{F,0}}{\ln(C_{F,T}) - \ln(C_{F,0})} \ln\left(\frac{Q_{cement,T}}{Q_{cement,0}}\right) \quad (15)$$

$$\Delta^{sha-F} = \frac{C_{F,T} - C_{F,0}}{\ln(C_{F,T}) - \ln(C_{F,0})} \ln\left(\frac{R_T}{R_0}\right) \quad (16)$$

$$\Delta^{tra-F} = \frac{C_{F,T} - C_{F,0}}{\ln(C_{F,T}) - \ln(C_{F,0})} \ln\left(\frac{H_T}{H_0}\right) \quad (17)$$

$$\Delta^{fix} = \frac{C_{F,T} - C_{F,0}}{\ln(C_{F,T}) - \ln(C_{F,0})} \ln\left(\frac{CE_{F,T}}{CE_{F,0}}\right) \quad (18)$$

$$\Delta^{eff-F} = \frac{C_{F,T} - C_{F,0}}{\ln(C_{F,T}) - \ln(C_{F,0})} \ln\left(\frac{I_{T,T}}{I_{T,0}}\right) \quad (19)$$

$$\Delta^{act-P} = \frac{C_{P,T} - C_{P,0}}{\ln(C_{P,T}) - \ln(C_{P,0})} \ln\left(\frac{Q_{cement,T}}{Q_{cement,0}}\right) \quad (20)$$

$$\Delta^{sha-P} = \frac{C_{P,T} - C_{P,0}}{\ln(C_{P,T}) - \ln(C_{P,0})} \ln\left(\frac{R_T}{R_0}\right) \quad (21)$$

$$\Delta^{tra-P} = \frac{C_{P,T} - C_{P,0}}{\ln(C_{P,T}) - \ln(C_{P,0})} \ln\left(\frac{H_T}{H_0}\right) \quad (22)$$

$$\Delta^{act-E} = \frac{C_{E,T} - C_{E,0}}{\ln(C_{E,T}) - \ln(C_{E,0})} \ln\left(\frac{Q_{cement,T}}{Q_{cement,0}}\right) \quad (23)$$

$$\Delta^{eff-E} = \frac{C_{E,T} - C_{E,0}}{\ln(C_{E,T}) - \ln(C_{E,0})} \ln\left(\frac{I_{El,T}}{I_{El,0}}\right) \quad (24)$$

$$\Delta^{Celec} = \frac{C_{E,T} - C_{E,0}}{\ln(C_{E,T}) - \ln(C_{E,0})} \ln\left(\frac{CE_{elec,T}}{CE_{elec,0}}\right) \quad (25)$$

7.2. *Technological abatement country by country*

7.3. *Overallocation country by country*

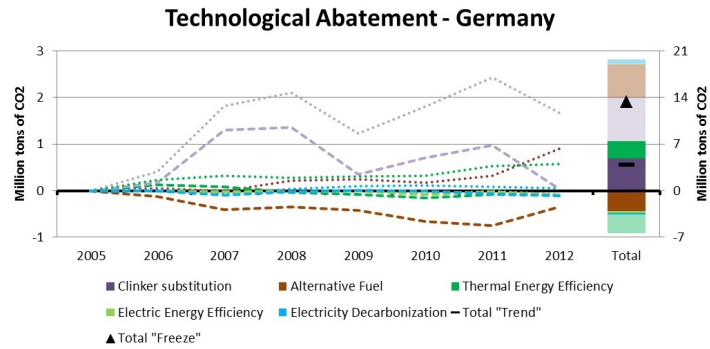


Figure 22: Technological abatement in Germany. The curves on the left side show the abatement due to the different effects under the “Freeze” scenario (dotted line) and the “Trend” scenario (dashed line). The histogram on the right gives the sum of abatements over the years, in full color for the “Trend” scenario, and in full color *plus* faded color for the “Freeze” scenario.

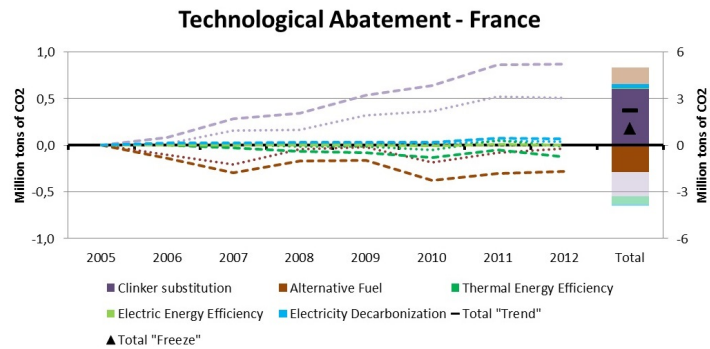


Figure 23: Technological abatement in France.

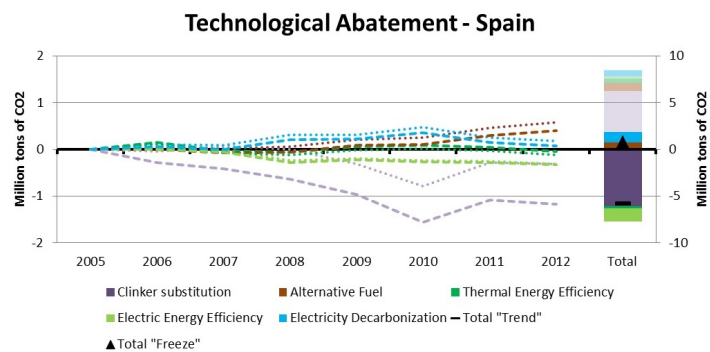


Figure 24: Technological abatement in Spain.

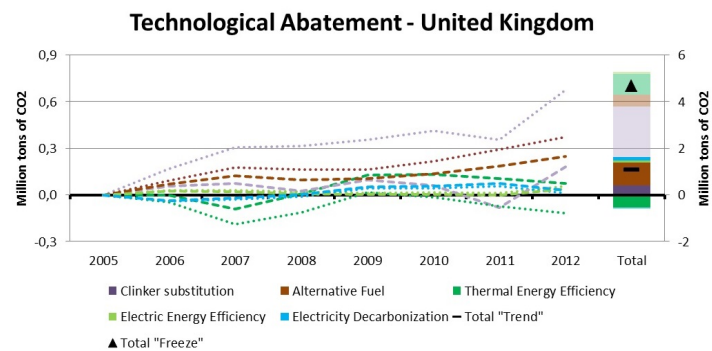


Figure 25: Technological abatement in the UK.

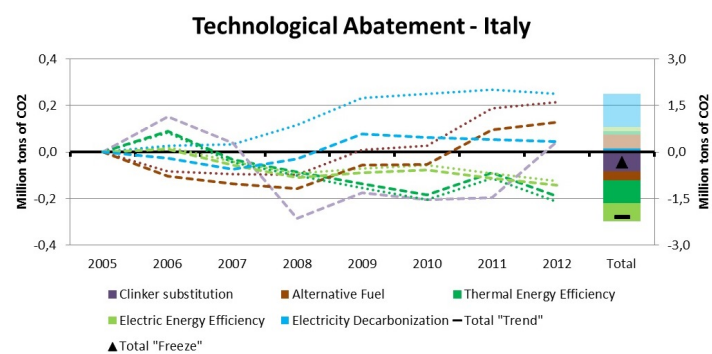


Figure 26: Technological abatement in Italy.

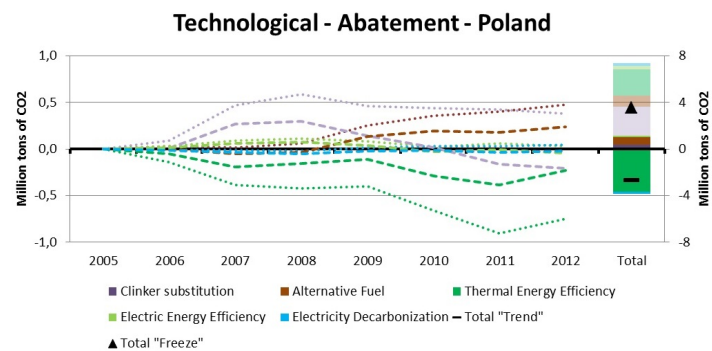


Figure 27: Technological abatement in Poland.

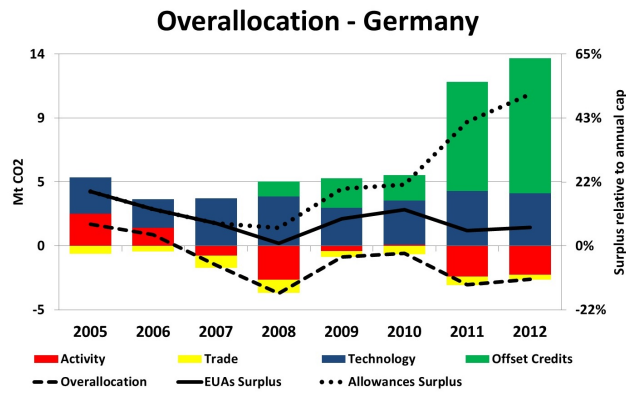


Figure 28: Overallocation in Germany.

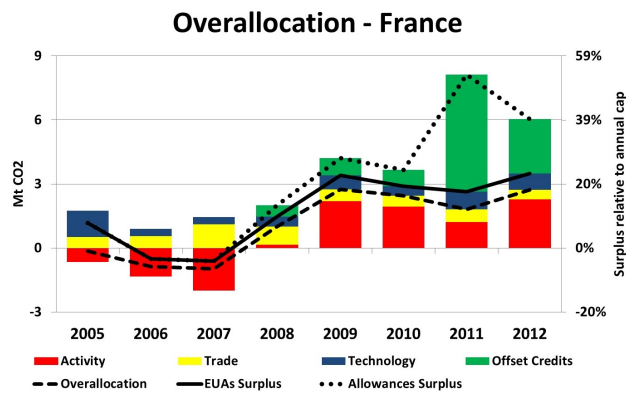


Figure 29: Overallocation in France

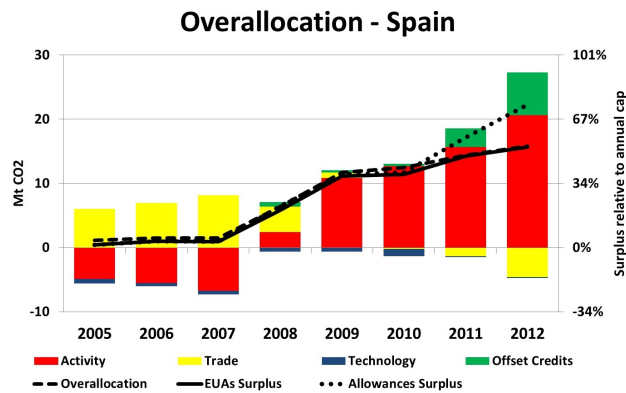


Figure 30: Overallocation in Spain

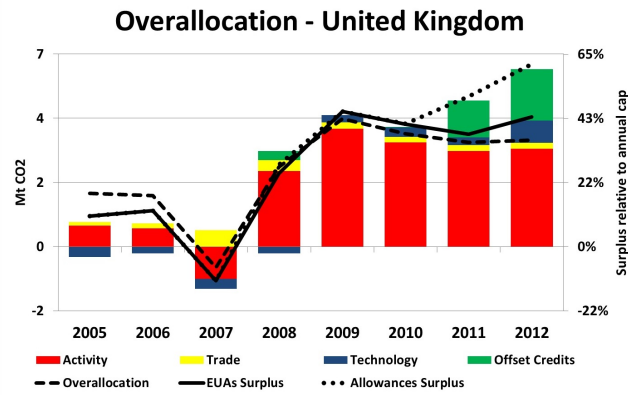


Figure 31: Overallocation in the UK

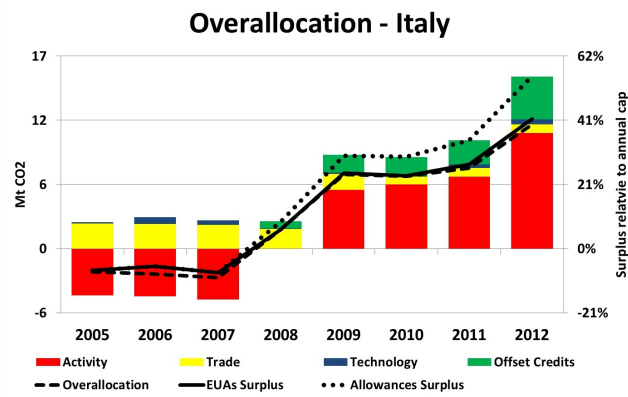


Figure 32: Overallocation in Italy

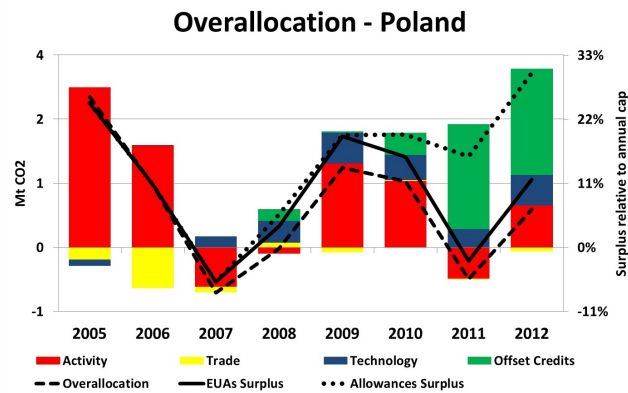


Figure 33: Overallocation in Poland